CHEMICAL WEED CONTROL

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BY

D. JAMES MORRE'

DOROTHY A. WERDERITSH

JHRP

JOINT HIGHWAY RESEARCH PROJECT

PURDUE UNIVERSITY AND

INDIANA STATE HIGHWAY COMMISSION

Final Summary Report

Part III

CHEMICAL WEED CONTROL

TO: J. F. McLaughlin, Director
Joint Highway Research Project

July 26, 1972

Project: C-36-48C

FROM: H. L. Michael, Associate Director
Joint Highway Research Project

File: 9-5-3

The attached Final Summary Report on Part III of the HPR Part II Research Study "Research in Roadside Development and Maintenance" is submitted as fulfillment of the objectives of Part III "Chemical Weed Control". The Report has been authored by the principal investigator on the Study, Dr.D. James Morre.

The Report presents a summary of the various portions of this Study Part - roadside weed surveys, physiology of herbicide action and evaluation of environmental safety of roadside herbicides, development of specific new weed control practices, and the development of fall herbicide applications for control of roadside weeds. Much of the information contained herein has and is being applied by the Landscape Division of the ISHC and some is proposed for further study and implementation in a new Study which has been forwarded for approval. The savings to the ISHC from the results of this portion of this Study are substantial and are noted in the attached Report.

The Report will also be submitted to the ISHC and the FHWA for review, comment and approval.

Respectfully submitted,

Harold L. Michael

Harold L. Michael
Associate Director

HLM:ms

cc:
W. L. Dolch
R. L. Eskew
W. H. Goetz
W. L. Grecco
M. J. Gutzwiller
G. K. Hallock
R. H. Harrell
M. L. Hayes
C. W. Lovell
G. W.Marks
R. D. Miles
J. W. Miller
C. F. Scholer
M. B. Scott
J. A. Spooner
N. W. Steinkamp
H. R. J. Walsh
E. J. Yoder

Final Summary Report Part III

RESEARCH IN ROADSIDE DEVELOPMENT AND MAINTENANCE

CHEMICAL WEED CONTROL

by

D. James Morre
Professor, Department of Botany and Plant Pathology
Purdue University

with the assistance of

Dorothy A. Werderitsh
Department of Botany and Plant Pathology
Purdue University

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The contents of this report reflect the views of the author who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

Purdue University
West Lafayette, Indiana
July 26, 1972

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ABSTRACT

The studies of this report were initiated in 1965 as part of an expansion of an earlier project titled "Chemical Weed Control". Objectives were evaluation of herbicides and herbicide combinations for roadside weed control, and control of difficult and obnoxious weeds. Improved understanding of the action of herbicides on plants and environmental safety of roadside herbicides were also objectives of the study. These considerations became increasingly important to the wise evaluation of effects of herbicides on the total environment.

Roadside weed surveys were conducted yearly from 1966 through 1971. Counts varied from less than 50,000 to nearly 1,000,000 weeds per mile. Species were determined and grouped into several categories. A major benefit was to give direction to the research program by identifying the seriousness of specific weed problems. Sources of economic losses to weeds were identified with increased mowing costs and weakening of turf as major considerations.

The modes of action of the important general roadside herbicides 2,4-D, 2,4,5-T and Tordon were studied in detail in the laboratory investigations. The findings have pointed to major improvements in weed control practices. Shown was the desirability of applying herbicides to perennial plants in the fall when materials are normally moved from shoots to underground plant parts. A key reaction in the mode of action of the auxin herbicide 2,4-D was discovered and characterized. The mode of action of Tordon was found to be similar or identical to that of 2,4-D. Amine formulations of 2,4-D were found to present no potential hazard to fish and algae or phytoplankton from

normal roadside use practices. Tordon was also shown to be non-toxic, but some ester formulations of herbicides were found to cause problems. Following recommendations derived from these studies, use of 2,4-D along roadsides in Indiana was restricted to amine formulations beginning with the fall of 1971. Other studies were concerned with investigations of new solvents such as dimethulsulfoxide (DMSO) or non-phytotoxic oils for application of herbicides to increase effectiveness.

Development of specific new weed control practices was concerned principally with Tordon - 2,4-D combinations and 2,4-D - CIPC combinations. Tordon - 2,4-D combinations have proven to be potent herbicides for control of a wide range of broad-leaved herbaceous and woody roadside vegetation without injury to desirable species. Difficult-to-control perennial species such as common milkweed and canada thistle were especially susceptible to Tordon. Studies showed that a significant portion of the Tordon necessary for control of these species can be replaced by less-expensive phenoxy herbicides, such as 2,4-D without reducing the overall effectiveness of the treatment. Variations in treatment methods have included tests with truck-mounted equipment and mixtures applied as invert emulsions or using other types of drift control procedures. A combination treatment with 1 lb/A of CIPC (a carbamate herbicide) followed several weeks later by 1 lb/A of 2,4-D was developed for control of wild garlic and yellow nutsedge. Repeat applications over a 2 year period have given greater than 90% control of both these species.

With most perennial and biennial species, treatment in the fall when translocation of assimilates was largely to below ground parts

was found most effective in preventing regrowth than were treatments applied to stages of rapid growth when translocation of assimilates was largely to the tops. This observation resulted in a new concept of applying herbicides in the fall for maximum effectiveness and minimum hazard to environmental quality and field crops adjacent to sprayed areas. Control has been achieved with common milkweed, whorled milkweed, canada thistle, wild parsnip, wild carrot, plantains, dandelion, curled dock, and other problem broad-leaved weeds as well as several brush species. Applications are in late August or September. Attempts to determine a basis for lack of effectiveness of herbicides on Johnsongrass were unsuccessful.

In 1971, approximately 1,500 miles of highway throughout the State of Indiana received a fall application of 2,4-D between September 15 and October 15 under the state spraying program by contract. Evaluations were made before and after spraying and the treatment gave weed control ranging from 80% to greater than 90% depending on the species and the care taken to apply the material correctly. By using more potent herbicides, we have been able to maintain turf in a weed-free conditions for at least 2 years following a single fall application with no injury to grass. This means that only one application every 3 years would be required. The findings point to the possibility of an eventual 3-year (environmentally safe) spraying rotation in combination with one-cycle mowing which can be developed into a maximum-benefit, low-cost maintenance program for Indiana roadsides with cost savings in excess of $300,000 annually.

"HIGHLIGHT" SUMMARY

Implementation of research results obtained under this Joint Highway Research Project has established the effectiveness of fall applications of herbicides to control problem weeds along roadsides. Applications were made from September 1 until the first killing frost. Only environmentally safe amine forms of the herbicide 2,4-D were recommended. As the first killing frost approaches, hard-to-kill, perennial weeds move all available materials into the underground parts. Herbicides applied at this time will reach the underground parts through the natural translocation activity of the plant at a time when these parts are most susceptible to the killing action of the herbicide. Dandelion, plantain, buckhorn, wild carrot, wild parsnip, milkweed, Canadian thistle, dock and other problem roadside weeds are among those susceptible to fall applications.

An important advantage of fall applications of herbicides is that of environmental safety. In the fall, desirable plants in cropland, gardens, etc. have completed their growth and escape the herbicide. Problems of drift onto soybean or tomato fields are eliminated since the growing season is over. By the following spring soil residues are completely dissipated especially with the biodegradable herbicide 2,4-D.

In 1971, approximately 1,500 linear miles of highway received a fall application of 2,4-D between September 15 and October 15 under the Spraying Program by Contract. Evaluations of test plots throughout the state showed the treatment to be extremely effective with weed control ranging from 85% to over 95%. Implementation of the fall spraying program resulted in a direct cost saving to the State of Indiana from the Herbicide Treatment Program by Contract alone of an estimated $60,000 annually. These figures do not include increased weed control and safety or reduced mowing costs.

Other research projects completed include development of spot treatments for localized infestations of problem weeds; evaluation of mowing practices; vegetation control in cracks and on stabilized shoulders; mode of herbicide action studies; and evaluation of herbicides for environmental safety. Mechanical and chemical methods combined provide a 3-year (environmentally safe) spraying rotation with minimum mowing to give even greater cost savings and without deterioration of existing turf.

Rights-of-ways are designed for safety and convenience. They should be kept as corridors of open turfed areas to provide the features of safety, beauty and convenience for which they were intended. Maintenance of these broad turfed areas by mechanical and chemical methods must continue. It is to our advantage that we maintain a healthy turf along Indiana roadsides but at the lowest possible cost to the State.

INTRODUCTION

Research on this total study was originally titled "Chemical Weed Control" and was initiated in June of 1961. It was conducted by members of the Department of Botany and Plant Pathology of the School of Agriculture in cooperation with the Roadside Improvement area of the Indiana State Highway Commission.

The research included study of the use of soil sterilants around signposts and other locations where manual cutting of the grass is necessary. A number of different herbicides, application rates, and application methods were used as variables in these tests. The research also has included study of the control in the southern area of the state of the hardy perennial, Johnson grass; investigation of the control of wild garlic and other pest weeds; a study of the use of a growth inhibitor on grasses; and research on the length of time which herbicides remain active in the soil. This latter research included a determination of the soil constituents that influence microbial decomposition of herbicides.

Reports on this part of this study were:

(1) W. J. Farmer, "A Model System for the Investigation of the Effect of Soil Particles on Microbial Decomposition of Herbicides", JHRP Report, Purdue University, February 1964.

In early 1965 an expansion of the project was approved to include research in the other two parts previously discussed. Objectives of this Part III of the study continued to be an evaluation of herbicides and herbicide combinations for roadside weed control. Of special interest was control of difficult and obnoxious roadside weeds. An

improved understanding of the action of herbicides on plants and environmental safety of roadside herbicides were also objectives of the study. These considerations were deemed important to the wise evaluation of effects of herbicides on the total environment.

PART I

ROADSIDE WEED SURVEYS -- 1966 - 1971

ROADSIDE WEED SURVEYS -- 1966 - 1971

1. Scope and objectives: The purpose of this phase of the study was to identify problem roadside weeds, to evaluate losses due to weeds along roadsides and to provide estimates of weed density and distribution in roadside situations. The results of these studies were to provide a basis for weed control recommendations and to aid in establishing priority problem weeds for initial study.

2. Introduction: Information on the nature and extent of roadside weed problems in Indiana was not available at the time this study was initiated. To our knowledge our studies are the only ones of their kind carried out for the State of Indiana.

3. Method of approach: Initial surveys were conducted in 1966 during the months of July and August on a) Highway 43 from Lafayette, south to Jct. 36, west to Rockville and southwest on Highway 41 to Terre Haute, b) Highway 52 southeast to Lebanon and Highways 32 and 38 east to Richmond, and c) a 30 mile portion of Highway 53 north from Montmorenci to Jct. 24. Similar studies were continued in 1967, 1968, 1969 and 1970.

In 1971, a quantitative evaluation procedure was initiated as follows:

Selection of test plots: Test plots were selected at the discretion of the inspector. They were designated on the inspection form as "selected weedy" to provide maximum number of species or as "representative" to approximate the average situation for the highway segment evaluated.

Designation: Each highway segment was designated by the number and direction, e.g. 43W. The plot location was indicated as to county and number of miles (to the nearest 0.1 miles) from a

convenient landmark locatable on a district map (preferably a major road junction or county line) e.g. 43 W, Putnam County, 3.6 miles west of Park County line.

Each test plot was given a code designation consisting of:

a) The first initial of the last name of the inspector

b) The first letter of the district in which the plot is located

c) The number and direction of the highway segment

d) And the sample number on that particular highway segment.

For example M-C-43W-1 would indicate Morré, Crawfordsville District, Highway 43W and the first test location on that highway segment, in that district, evaluated by that inspector. This number appeared on all data sheets, photographs, etc. associated with that test plot as well as the official inspection sheet.

Sampling procedure: All broad-leaved weeds plus wild garlic were counted in an area of 10 square feet. Three different portions of the right-of-way were sampled:

a) Adjacent to the pavement (designated as IS - Improved Shoulder or S - Shoulder)

b) Midway between the pavement edge and the fence or fence line (designated as C - Center)

c) Approximately 6 inches back from the fence or fence line (designated as F - Fence)

The first set of counts were taken on the right side of the road facing in the direction of travel (if you are sampling 47W, you must face in the direction of travel of 47W not in the direction of travel of 47E). The sample zones for this series was

was designated as IS R or S R, C R and F R.

Counts were taken every 25 feet (about 5 paces) to give a total of 10 counts for each of the three sample zones in a linear distance of about 250 feet.

When the last of the 10 counts was completed, identical procedure was repeated for the left side of the road. The sampling zones will be designated as IS L or S L, C L and F L.

Also measured was the average height of bluegrass in inches on both sides of road and the approximate width (in feet) of the right-of-way (pavement edge to fence line).

4. Major findings:

Group I. Of general occurrence

A. Numerous, example Buckhorn Plantain (Plantago lanceolata)

B. Intermediate density, example Curled Dock (Rumex crispus)

C. Scattered as individual plants, example Common Mullein (Verbascum thapsus)

Group II. Of general occurrence but in scattered infestations

A. Numerous when found, example Wild Mustard (Brassica kaber)

B. Intermediate density, example Chickory (Cichorium intybus)

C. Scattered as individual plants, example Catnip (Nepeta cataria)

Group III. Of occurrence only in special habitats

A. Numerous when found, example Yellow Nut Sedge (Cyperus esculentus)

B. Intermediate density, example Spiderwort (Tradescantia spp.)

C. Scattered as individual plants, Prickly Pear Cactus (Opuntia spp.)

The following plants were classified IA: Buckhorn Plantain (Plantago lanceolata), White Clover (Trifolium repens) Dandelion (Taraxacum officinale); ID: Curled Dock (Rumex crispus), Red Clover (Trifolium pratense), Common Ragweed (Ambrosia artemisifolis), Giant Foxtail (Setara faberii), Green Foxtail (Setaria viridis) Yellow Foxtail (Setaria lutescens), Poison Ivy (Rhus toxicodendron); IC: Common Mullein (Verbascum thespus), Tall Lettuce (Lactuca canadensia), Common Milkweed (Asclepius syriaca); IIA: Wild Mustard (Brassica kaber), Fleabane (Erigarea atrigonus), Wild Parsnip (Pastinaca sativa), Field Bindweed (Convolvulus arveasis), Horseweed (Ambrosia trifida), Soapwort (Saponaria officinelis), Day Lily (Hamerocallis fulva), Knotweed (Polygonum aviculare), Quackgrass (Agropyron repens) (Northern), Wild Garlic (Allium vineale) (Southern), Johnson Grass (Sorghum halepense) (Southern); IIB: Chickory (Chicorium intybus), Marestail (Erigeron canadensis), Canada Thistle (Cirsina arvence), Broadleaf Plantain (Plantago major), Hedge Bindweed (Convolvulus sepium), Jimson Weed (Datura stramonium), Whorled Milkweed (Asclepies verticillata), Smartweed (Polygonum pensylvanicum and related species); IIC: Catnip (Napeta cataria), Bull Thistle (Cirsium vulgare), Trumpet Creeper (Campsis radicans), Wild Grape (Vitus spp.), Asparagus (Asparagus officinalis), Yucca (Yucca glauca), Blue Vervain (Verbena hastata), Ironweed (Vernonia altissima); IIIA: Yellow Nut Sedge (Cyperus esculentus), Horsetail (Equisetum spp.), Cattail (Typha latifolia), Arrowhead (Sagittaria latifolia); IIIB: Spiderwort (Tradescantia spp.), Reed Canary Grass (Phalaris arundinaceae); IIIC: Prickly Pear Cactus (Opuntia spp.).

As a byproduct of these studies, a Key to Plant Families based on vegetative characteristics was formulated as an aid to further studies of this type as well as keys based on floral and fruiting structures and a key to aquatic families.

In the 1971 survey, quantitative data was obtained which is representative of approximately 1,500 linear miles of highway throughout the State of Indiana. Counts varied from over 700,000 weeds per mile (SR 27, Fort Wayne District) to less than 50,000 weeds per mile (Ind. 421, LaPorte District). An example of the type of information obtained is provided in Table I. Generally, those roads included in a regular herbicide spraying program were in the 50,000 to 100,000 weeds/mile category while those roads which were previously unsprayed averaged over 500,000 weeds per mile.

The major economic losses due to roadside weeds were traced to increased mowing costs (more mowing cycles were required due to fast growing weeds rather than grass), weakening of turf (weeds, even short weeds like dandelion and plantain, kill the turf by shading and competition only to die back during the winter to leave patches of bare soil open to erosion) and shortening of the life of stabilized shoulders. Evaluations of unmaintained rights-of-way show that tree seedlings and root sprouts can become established within one year unless at least a minimal maintenance schedule is maintained. Trees close to the pavement represent a traffic hazard and must be removed. The turf must then be reestablished to prevent further erosion.

5. Research implementation: Findings of this study have given direction to the entire program. Specific findings have been transmitted to the Maintenance Division of the Indiana State Highway Commission and were

presented at the 1972 Road School and the 1971 Indiana Plant Food and Agricultural Chemical Conference. The results from the 1971 survey will be included as part of a detailed report on the effectiveness of the 1971-1972 Spraying Program by Contract scheduled for completion in late 1972. We anticipate that this report will be decisive in determining future directions for chemical control of weeds along Indiana roadsides.

6. Summary: Extensive weed surveys were conducted during July and August 1966 on Indiana Highways. Plants were grouped as: I. Of general occurrence; II. Of general occurrence but in scattered infestations; and III. Of occurrence only in special habitats. Subcategories included numerous species, species of intermediate density and plants scattered as individuals. A summary tabulation of results was presented.

7. Reports:

D. J. Morre, "A Key to Plant Families Using Leaves, Stems and Roots", JHRP Report, Purdue University, 1970.

D. J. Morre, "Fall Applications Control Next Years Weeds", Proceedings Indiana Plant Food and Agricultural Chemical Conference, 1971.

TABLE I

Weed counts taken in the fall of 1971 on SR 27 0.2 miles south of Jct. U.S. 224 in the Fort Wayne District

Weed Density	Knotweed	Lambsquarter	Red Clover	Wild Carrot	Common Ragweed	Dandelion	Sweet Clover
Weeds/mile	683,046	17,249	4,403	9,176	4,403	47,932	21,289
Weeds/acre	135,108	3,412	871	1,815	817	9,481	4,211

Weed Density	White Clover	Nodding Spurge	Prostrate Spurge	Plantain	3-Seeded Mercury	Bindweed
Weeds/mile	12,846	2,937	733	15,783	2,937	5,874
Weeds/acre	2,541	581	143	3,122	581	1,162

Weed Density	Poison Ivy	Horse Nettle	Common Milkweed	Canada Thistle	Common Thistle	Other Composites
Weeds/mile	733	1,466	367	9,545	367	2,937
Weeds/acre	143	290	73	1,188	73	581

PART II

PHYSIOLOGY OF HERBICIDAL ACTION

AND

EVALUATION OF ENVIRONMENTAL SAFETY OF ROADSIDE HERBICIDES

MECHANISM OF ACTION OF TORDON HERBICIDE (PICLORAM)

1. Scope and objectives: To determine the cellular and/or biochemical basis for the herbicidal action of Tordon (picloram) herbicide and compare its mode of action with that of the auxin herbicides 2,4-D and 2,4,5-T.

2. Introduction: Tordon is a broad spectrum herbicide introduced by the Dow Chemical Company in the early 1960s. It causes stem twisting and other formative effects in broad-leaved plants as part of its herbicidal action. The distortions are similar to those produced by the phenoxyacetic acids or auxin-type herbicides but Tordon herbicide is much more toxic to plants and more persistent than either 2,4-D or 2,4,5-T.

3. Method of approach: The growth-regulating properties of Tordon were compared in the laboratory with those of the known auxins and auxin herbicides indole-3-acetic acid (IAA) and 2,4-D, using a broad range of biological tests.

4. Major findings: Tordon was found to cause stem twisting and other formative effects in susceptible broad-leaved plants. The distortions of the growing stems and leaves were similar to those produced by the phenoxyacetic acids, 2,4-D and 2,4,5-T. Qualitatively, Tordon, 2,4-D and 2,4,5-T caused similar stimulations of polarized cell elongation in various kinds of stem sections floated on solutions containing the growth regulator. 2,4-D, indoleacetic acid and Tordon all supported growth of tissue explants in culture, inhibited root growth, induced cell wall loosening, produced stem curvature and other formative effects, promoted loss of chlorophyll and induced abscission responses. Thus, by all criteria available, Tordon should be classified as an auxin herbicide along with 2,4-D and 2,4,5-T (Table II). A kinetic analysis of root growth inhibition indicated a single mode of action for Tordon and 2,4-D and the minimal structural requirements for auxin activity were found to be met by Tordon. The greater herbicidal effectiveness

TABLE II

COMPARISON OF IAA, 2,4-D AND TORDON ON PLANT GROWTH AND DEVELOPMENT RESPONSES

ASSAY	IAA	2,4-D	TORDON
Formative effects (Stem, twisting, and curvature, cell proliferation, formation of adventitious roots)	+	+	+
Loss of chlorophyll from treated leaves	+	+	+
Promotion and inhibition of polarized straight growth	+	+	+
Cell swelling at supraoptimal concentrations	+	+	+
Growth inhibited by antiauxins	+	+	+
Receptor site competition with other auxins in coleoptiles	+	+	+
Support of callus growth in culture	+	+	+
Cell wall loosening	+	+	+
Inhibition of root growth	+	+	+
Receptor site competition with other auxins in roots		+	+
Root initiation	+	+	+
Parthenocaopic fruit set	+	+	+
Seed germination effects	+	+	+
Abscission effects	+	+	+
Bean curvature	+	+	+
Avena curvature	+	-	-
Promotion of cell elongation with intact cuttings	-	-	+

of Tordon was attributed to increased mobility and resistance to breakdown within the plant. A remarkable ability of Tordon to increase the growth of intact shoot cuttings was not shared by either 2,4-D or IAA and neither Tordon nor 2,4-D were transported in a polar manner in the Avena curvature test.

Kinetic analyses of Tordon - 2,4-D interactions revealed that mixtures often resulted in greater growth promotion with excised sections than the same amounts of each herbicide alone. This apparent synergism between 2,4-D and Tordon in mixtures was observed in a variety of bioassays as well as in greenhouse and field studies with several plant species.

5. Research implementation: An understanding of the mode of action of Tordon greatly facilitated rapid development of herbicide mixtures involving this herbicide and the nature of the interactions between Tordon and 2,4-D or Tordon and 2,4,5-T in mixtures. Early work lead to a bioassay procedure specific for detection of Tordon in soil and plant extracts. The results of the study have also aided considerably in our evaluation of the safety of this material for inclusion in a roadside spraying program.

6. Summary: The mode of action of Tordon is similar or identical to that of 2,4-D at the cellular level. Herbicidal effectiveness is attributed to greater stability and mobility within the plant.

7. Reports:

W. Eisinger and D. J. Morre, "Tordon, A New Synthetic Growth Regulator", Proceedings of the Indiana Academy of Science for 1965.

W. Eisinger, D. J. Morre and C. E. Hess, "Promotion of Plant Growth by Tordon Herbicide", Published in Down to Earth, a publication of the Dow Chemical Company, Midland Michigan, Spring 1966.

D. J. Morre, W. R. Eisinger and H. W. Mussell, "Tordon - 2,4-D - Dimethylsulfoxide Combination Herbicides for Use in Roadside Development", JHRP Report, Purdue University, November 1967.

W. R. Eisinger, S. Krawiec, D. J. Morre and R. J. Hull, "Picloram: Its Auxinic Properties and Interactions with 2,4-D", Proceedings Weed Science Society of America, 1968.

S. Krawiec and D. J. Morre, "Interactions of Tordon Herbicide Applied in Combinations", Published in Down to Earth, a publication of the Dow Chemical Company, Midland Michigan, Winter 1968.

W. R. Eisinger and D. J. Morre, "Growth-Regulating Properties of Picloram, 4-Amino-3,5,6-Trichloropicolinic Acid", Published in Canadian Journal of Botany, 1971.

MECHANISM OF ACTION OF 2,4-D AND RELATED AUXIN HERBICIDES

1. Scope and objectives: To determine the cellular and/or biochemical basis for the herbicidal action of 2,4-D and related auxin herbicides.

2. Introduction: The mechanism of action of 2,4-D and related auxin herbicides and eluded scientists for over 30 years. Understanding the mode of action is expected to lead to new concepts of chemical weed control, greater environmental safety and a more fundamental understanding of how plants grow.

3. Method of approach: Mode of action studies have been in progress in the the laboratory since the project on Research in Roadside Development was expanded in 1965 to include chemical weed control. A large number of approaches to understanding the mode of action of the herbicide were followed but until recently none were successful.

4. Major findings: In late 1971 and early 1972, working in close cooperation with the laboratory of Prof. Joe H. Cherry in the department of Horticulture, we demonstrated that 2,4-D combines with the cell membrane of the plant to release a messenger molecule or "factor" which migrates to the interior of the cell. Here, the factor causes a change in synthesis of RNA (ribonucleic acid) from the genetic material of the cell's nucleus (Fig. 1).

5. Research implementation: We plan to utilize the information to characterize the initial events of 2,4-D action, locate the initial binding site and determine what aspects of the reaction can be manipulated to result in enhanced or diminished herbicidal action.

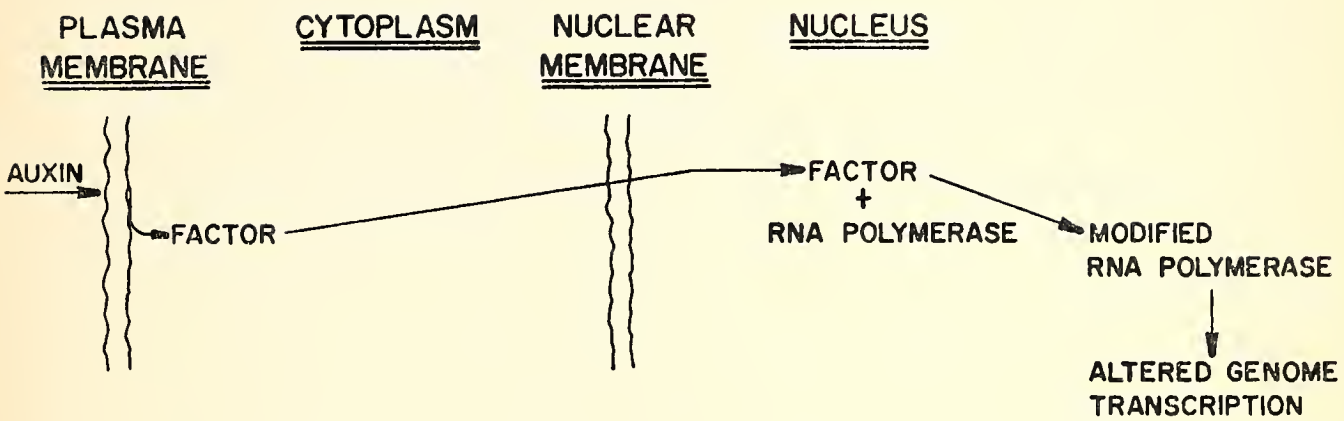

Figure 1. Outline of the mechanism of action of the auxin herbicide 2,4-D. Laboratory studies show that 2,4-D (auxin in the diagram) interacts with a factor within the cell membrane or plasma membrane of the plant. The factor then moves to the interior of the cell, crosses the membrane surrounding the cell's nucleus and there regulates the production of RNA (ribonucleic acid) through interaction with an enzyme called RNA polymerase.

6. Summary: A key reaction in the mode of action of the auxin herbicide 2,4-D was discovered and partially characterized. Further study is expected to provide new approaches to chemical weed control.

7. Reports:

W. J. VanDerWoude, C. A. Lembi and D. J. Morre, "An Effect of 2,4-D Herbicide on the Cell Surface Membrane of Onion Stem Explants", JHRP Report, Purdue University, July 1971.

J. W. Hardin, J. H. Cherry, D. J. Morre and C. A. Lembi, "Enhancement of RNA Polymerase Activity by a Factor Released by Auxin from Plasma Membrane", to be submitted to the Proceedings of the National Academy of Sciences, Washington, D. C.

DIMETHYLSULFOXIDE (DMSO) AS A HERBICIDE CARRIER AND ADJUVANT

1. Scope and Objectives: The research undertaken was concerned with 1) the extent to which DMSO would increase herbicidal effectiveness through facilitated uptake of the herbicide; 2) the mechanisms of DMSO-facilitated herbicide uptake; 3) DMSO phytotoxicity and 4) DMSO - herbicide combinations for use in roadside development.

2. Introduction: Dimethylsulfoxide (DMSO), a byproduct of the paper making industry, is an exceptionally powerful solvent for organic herbicides making a concentrated true solution with most herbicides, even with water-insoluble materials. It is easy and safe to use and DMSO by itself has an extremely low toxicity. Its ability to penetrate tissues and its solubility characteristics combined to indicate that DMSO was potentially useful as a carrier of herbicides in formulations for roadside development.

3. Methods of procedure: Preliminary laboratory investigations were followed by more extensive greenhouse tests and field studies. Studied were enhancement of herbicidal effects of 2,4-D and Tordon by application in DMSO, DMSO effects on membrane permeability, phytotoxicity of DMSO-containing solvents, greenhouse evaluations of DMSO - 2,4-D interactions and various attempts at field applications of the laboratory and greenhouse findings.

4. Major findings: In controlled laboratory investigations, an enhancement of 2,4-D and Tordon penetration and/or activity was observed when the herbicide was applied to plants using DMSO as the solvent. At least part of the enhancement was due to facilitated foliar penetration of the herbicide as a result of rapid penetration of the DMSO carrier. Turf grasses were found to be tolerant of even pure DMSO. A synergistic enhancement of 2,4-D toxicity by application in DMSO was observed in approximately 36 of 40 different species

of mature or seedling plants tested from 18 plant families in greenhouse studies. 2,4-D at a rate of ½ lb per acre, reduced onion fresh weight during a two week period following treatment and permitted relatively normal bulb formation. Application of the 2,4-D in DMSO, however, resulted in a 95% inhibition on fresh weight over the same time period and complete supression of bulbing. These results with onion prompted a field testing program involving 2,4-D - DMSO mixtures for wild garlic eradication along roadsides. Seven trials in 1966 plus additional trials in 1967, 1968, 1969 and 1970 comparing over 50 common roadside species of plants showed no evidence of a reproducible 2,4-D - DMSO or Tordon - DMSO interaction in the field.

5. Research implementation: The studies are an unfortunate example of something that worked exceptionally well in the greenhouse but failed in the field. Our findings generated considerable interest among other scientists working on the same problem and contributed substantially to an understanding of the mode of action of DMSO. The studies were largely abandoned in 1967 although additional field trials were conducted through 1970 on a limited scale.

6. Summary: Dimethyl sulfoxide (DMSO) showed exceptional promise in greenhouse studies as a solvent and carrier for herbicides herbicidal applications. It was shown to be completely ineffective under field conditions for reasons we still do not understand in spite of considerable research effort.

7. Reports:

H. W. Mussell, D. J. Morre and R. J. Green, "Response of Plant Tissues to Dimethyl Sulfoxide (DMSO)", American Society of Plant Physiology, 1965.

H. W. Mussell, W. Bucko, D. J. Morre and R. J. Green, "Some Effects of Dimethyl Sulfoxide Upon Seed Germination, Plant Growth and Herbicide Activity", Proceedings Indiana Academy of Science for 1965.

D. J. Morre, W. R. Eisinger and H. W. Mussell, "Tordon - 2,4-D - Dimethylsulfoxide Combination Herbicides for Use in Roadside Development", JHRP Report, Purdue University, November 1967.

H. W. Mussell, D. J. Morre and R. J. Green, "Acceleration of Bean Leaf Abscission by 2,4-Dichlorophenoxyacetic Acid Applied in Dimethylsulfoxide", Published in Canadian Journal of Plant Science, 1967.

A LABORATORY BIOASSAY TO DETERMINE RATIOS OF HERBICIDES IN MIXTURES

1. Scope and objectives: Laboratory bioassay procedures using leaf discs were initiated for precise determination of the optimum ratio of 2,4-D and 2,4,5-T in mixtures to provide efficient control of a wide range of herbaceous broadleaf species. At the time this work was initiated a midsummer application of 3/4 gal 2,4-D amine + 3/4 gal 2,4,5-T amine per 100 gal water was included as part of the spraying program by contract.

2. Introduction: By employing combinations, one herbicide can overcome weaknesses of other herbicides in the combination. Combinations also offer the possibility of broadening the spectrum of herbicidal selectivity by synergistic action. Properly chosen combinations insure against unfavorable weather conditions and offer a method of extending the duration of control over longer periods. The present study was designed to determine what amount of a more costly herbicide (2,4,5-T) was required in a mixture with a less costly herbicide (2,4-D) for effective weed control. Field studies showed that varying the herbicide ratios resulted in only small differences in weed control. These differences were difficult to evaluate with certainty in the field. Yet, small differences might provide substantial cost savings even though the amounts represent only a few cents per acre. A laboratory procedure can offer more accurate controls and a clearer picture of differences in growth as opposed to standard field testing. Small, but significant, effects can be easily overlooked in the field. Laboratory testing provides considerable savings in time and money when used in conjunction with field testing. To

evaluate this possibility, an accurate and sensitive laboratory bioassay involving leaf discs was developed and tested to determine the optimum ratio of 2,4-D and 2,4,5-T in mixtures.

3. Method of approach: Discs, 7 mm in diameter, were cut from the leaf blades, avoiding larger veins. These discs were placed in covered petri plates on filter paper saturated with sufficient herbicide solution to allow each disc to be surrounded by a meniscus of solution. The dishes were then exposed to continuous fluorescent light for 26 hours. Discs were weighed at 2 and 26 hours to determine growth. In addition to herbicides, each solution contained 8×10^{-2} M potassium nitrate to enhance control growth. All herbicides were tested at a concentration of 6.25×10^{-4} M, which averaging a large number of species, resulted in 50% inhibition of growth with 2,4-D. Species tested included garden bean, plantain, lamb's quarter, yellow rocket, sweet clover, smartweed, bindweed, mouseeared chickweed, mare's tail and velvet leaf.

4. Major findings: With few exceptions, growth of leaf discs was inhibited more by 2,4,5-T than 2,4-D (Fig. 2) confirming that 2,4,5-T is a more potent herbicide than 2,4-D. The surprising observation was that for most species a mixture of 2,4-D and 2,4,5-T was no more inhibitory than 2,4-D alone (Figs. 2B and D). This included the 2,4-D-resistant, 2,4,5-T-susceptible species, sweet clover as well as the 2,4-D-susceptible species lamb's quarter. For these species, treating roadsides with mixtures of 2,4-D and 2,4,5-T would seem to offer little advantage. Only with yellow rocket (Fig. 2A) and to some extent with plantain (Fig. 2C) did the discs respond to mixtures and only with yellow rocket did the addition of small quantities of 2,4,5-T to 2,4-D show a significant response. Laboratory studies show 2,4-D to have a greater affinity of binding to reactive sites in the plant's tissues and thus can effectively compete with 2,4,5-T in its herbicidal action. These findings confirm previous studies with Tordon-2,4-D combinations which indicate that

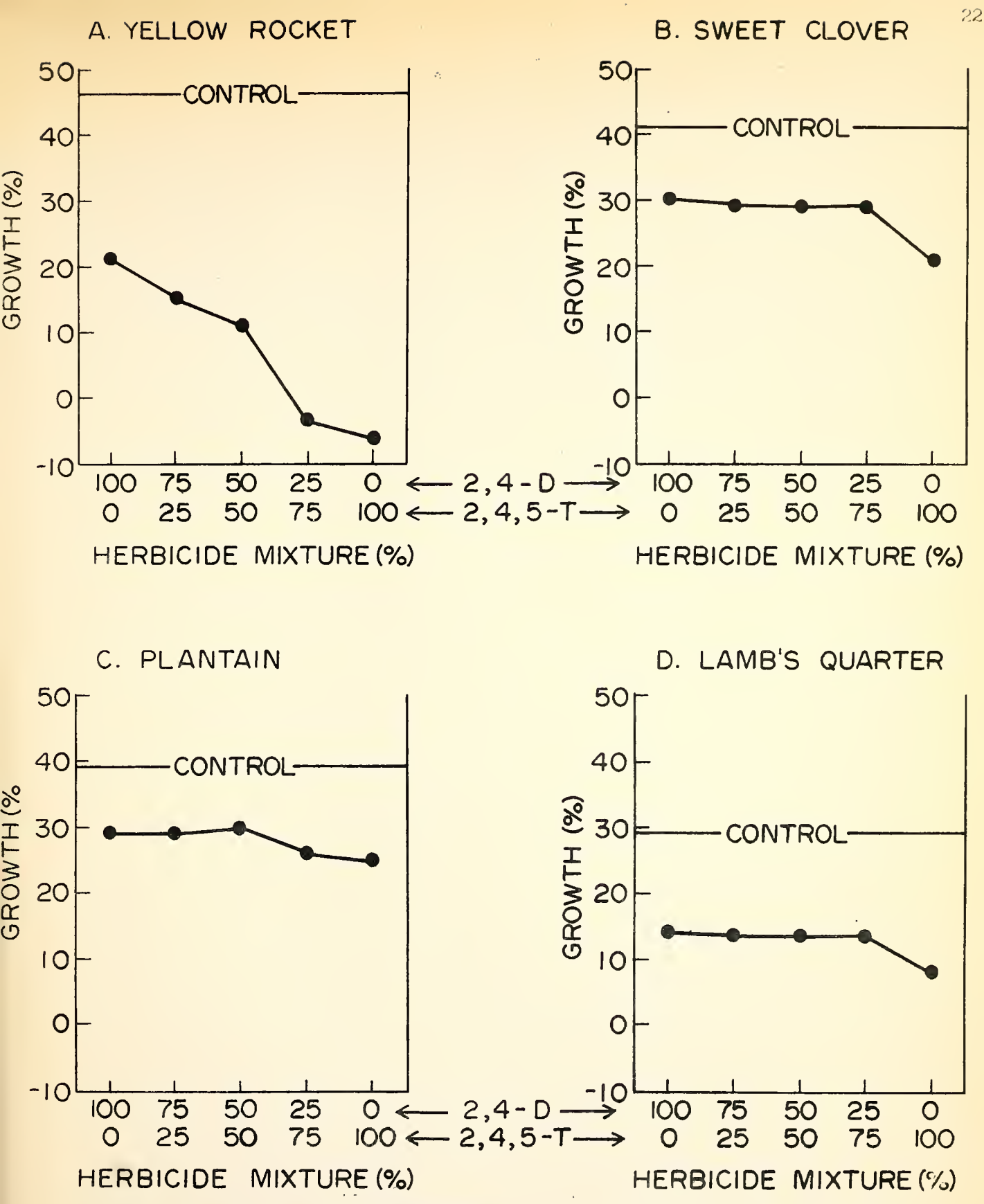

Figure 2. Sample results from the leaf disc bioassay method for determining proper ratios of different herbicides in mixtures. Growth is given as percent increase after 26 hours over the initial weight determined after 2 hours of equilibration with the test solution. The final concentration of herbicide (2,4-D, 2,4,5-T or 2,4-D plus 2,4,5-T) was constant at 6.25×10^{-4} M ae.

the addition of small quantities of a more potent herbicide (2,4,5-T) to large quantities of a less potent herbicide of similar mode of action (2,4-D) is wasted money.

5. Research implementation: Based on these findings in combination with field studies and (most important) the impending government ban on 2,4,5-T, it was recommended to the Division of Maintenance that the use of 2,4,5-T - 2,4-D mixtures for roadside weed control be discontinued in the spraying program by contract pending further investigation. This recommendation was accepted and the mixtures are no longer being employed in the contract program. The information was also passed on to district personnel with the recommendation that all general weed control operations be limited whenever possible to 2,4-D amine formulations. We find no specific objections to the use of 2,4,5-T for brush control, however. A suitable alternative to 2,4,5-T or 2,4-D - 2,4,5-T mixtures for brush control is not yet available. Current efforts are to make an amine formulation of Silvex available for roadside use. Even so, it will be less effective than 2,4,5-T amine which, under proper conditions of manufacture, offers no particular threat to the environment.

Summary: A simple laboratory procedure was developed which offers great potential for savings of money and time and which generates accurate information on effectiveness of herbicide combinations. It offers the additional advantage of permitting the testing of new herbicides without danger to the environment. The findings confirmed the ineffectiveness of small quantities of a potent herbicide when mixed with a less potent herbicide of similar or identical mode of action. Results with 2,4-D - 2,4,5-T combinations were combined with other findings to result in a recommendation for the discontinuance of 2,4,5-T in mixtures for general roadside weed control.

Reports: The findings of this study were communicated informally at a meeting with the District Maintenance Engineers at the State Highway Commission Offices in Indianapolis on May 10, 1971 and again on June 8, 1971 at the First Roadside Spraying Seminar at the State Highway Commission Research and Training Center, McClure Parke, Lafayette, Indiana. Many Landscape Supervisors and Contractors were in attendance at the second meeting.

ANATOMICAL AND PHYSIOLOGICAL STUDIES OF COMMON MILKWEED RELATED TO SEED PRODUCTION, RESISTANCE TO HERBICIDES AND HERBICIDE TRANSLOCATION

1. Scope and objectives: To study the anatomy and physiology of common milkweed in order to help understand why this plant is exceptionally resistant to herbicides and mowing treatments. Ultimately, the findings are to be utilized in other studies to attempt to overcome the resistance mechanisms.

2. Introduction: Common milkweed (Asclepias syriaca) is one of the most persistent roadside weeds in the Midwest. This is partially explained by the resistance of milkweed to 2,4-D and its ability to survive repeated mowing. A detailed study was undertaken to better understand the basis for the resistance of milkweed to mechanical and chemical weed control treatments.

3. Method of approach: Germination characteristics of milkweed seeds were determined and foliar translocation patterns of applied Tordon were compared with those of 2,4-D and 2,4,5-T using radioactive herbicides and whole-plant autoradiography. Paraffin embedded, sectioned and stained histological sections from various parts of the milkweed plant were prepared and examined in detail using the light microscope.

4. Major findings: Seeds of common milkweed have high viability and moderate longevity and are capable of emerging from considerable depth. The initial embryo dormancy of freshly harvested mature or immature seeds is overcome by normal winter conditions of high moisture and low temperature. The results show that mowing of plants must be done well in advance of seed pod development to be effective.

The translocation patterns of foliar applied Tordon were compared with those of 2,4-D and 2,4,5-T. Herbicides were applied alone and in combination

with an equal herbicide equivalent in all treatments. Red kidney bean was used as the test plant prior to experimentation with milkweed. All herbicides moved from the primary leaf via the symplast to growing regions of the plant. Tordon translocated to the shoot apex and developing leaves with little basipetal movement. Both 2,4-D and 2,4,5-T translocated equally to the shoot apex. Herbicide combinations did not significantly alter the distribution pattern exhibited by the herbicides applied alone. The findings show that herbicide translocation follows the assimilate translocation. Herbicide applications should be in the fall when assimilates are being translocated to below-ground parts.

As part of the investigation into the basis of herbicide resistance of milkweed, a study was undertaken to learn the anatomical and ontogenetic aspects of laticifers (latex or milk-producing cells) of this plant. Laticifers are present in stem and leaf tissue of both embryos and mature plants. No laticifers were observed in roots although they were present in the adventitious buds on rootstocks. Laticifers grow by intrusive symplastic expansion causing no injury to surrounding tissue. Laticifers in stems and leaves are located in cortical or mesophyll tissue usually in close proximity to the vascular bundles. Although no direct connection with the phloem was observed, the living laticifers are part of the symplast and thereby interconnected with all living cells via plasmodesmata. The function of laticifers in plants is not well understood. Most authorities believe they may be involved in the removal of waste products from adjacent tissue. Since laticifers in milkweed are present from the earliest growth stages and are near conducting tissues, it seems possible that some herbicides could be removed from the phloem and concentrated in laticifers where they would have no toxic action.

5. Research implementation: Subsequent testing of fall herbicide applications has borne out the importance of these findings and led to further implementation in the form of specific weed control recommendations.

6. Summary: The findings point to the desirability of scheduling herbicide applications for control of common milkweed in the fall when latex production is at a minimum and when translocation patterns favor translocation of herbicides from the shoots to below-ground plant parts.

7. Reports: The detailed findings have been prepared in manuscript form to be submitted for communication as technical research reports in appropriate scientific journals.

EVALUATION OF THE ENVIRONMENTAL SAFETY OF ROADSIDE HERBICIDES: EFFECTS ON AQUATIC ECOSYSTEMS

1. Scope and objectives: Effects of the roadside herbicides Tordon (picloram) and 2,4-D were tested from the standpoint of toxicity to fish and on the growth and development of 16 species of fresh water and marine algae and phytoplankton.

2. Introduction: The potential hazard of roadside herbicides to aquatic ecosystems from soil runoff or direct accidental contamination of water must be determined. Some contamination cannot be avoided and it is desirable that any roadside herbicide be non-toxic to fish and other forms of aquatic life.

3. Method of approach: Fresh water algae were grown in a medium composed of filtered soil water and pond water. Marine algae were grown in filtered soil water and sea water. Analytical Tordon (99%), technical tordon (91%), and biological grade 2,4-D (99%) were added directly to the growth medium. Other herbicides were formulated materials obtained directly from the manufacturer. Growth was determined using a spectrophotometer or from cell counts. Cells were also examined with light and electron microscopes to determine morphological changes. Fish were maintained in pond water with continuous aeration and an artificial diet. Fish mortality was recorded and at the end of the studies, fish were examined for tissue abnormalities. Livers were also examined in the electron microscope for cellular changes.

4. Major findings: The results show that the potential hazard of pure 2,4-D or Tordon to fish or algae from terestrial runoff water (concentrations of 0.1 ppm or less) or direct or accidental contamination (3 lb/A applied directly to 6" of water) is nil. Studies with formulated materials show that 2,4-D ester derivatives are substantially more toxic than the parent acid and that fish and phytoplankton kills will result at the 3 lb/A rate applied directly to water. Further studies will be necessary to determine what effects these

herbicides might have on subtile ecological shifts as well as to assess the effect of these herbicides in combination with other water pollutants. We could find no evidence for biological magnification of either 2,4-D or Tordon in algae. At very high concentrations, technical tordon was toxic to both algae and fish. Four known impurities present in technical Tordon were tested. Only one, 2-(3,4,5,6-tetrachloro-2 pyridyl) guanidine was found to be toxic. Even with technical Tordon, the LD_{50} to fish in the range of 10-500 ppm (depending on species, size and conditions of exposure) is acceptable and can be increased to exceed the solubility of Tordon in water by additional purification during manufacture.

5. Research implementation: In June 1971, a recommendation was made to the Indiana State Highway Commission that only non-toxic amine and salt formulations of 2,4-D be used for roadside spraying operations and that use of toxic ester formulations be discontinued. The recommendation was accepted and beginning with the fall of 1971, use of 2,4-D has been restricted to amine formulations.

6. Summary: Amine formulations of 2,4-D present no potential hazard to fish and algae or phytoplankton from normal roadside use practices. Tordon is equally non-toxic but additional testing will be required to select appropriate formulations should this material be adopted for widespread use in roadside weed control.

7. Reports (*REPRINT APPENDED)

J. H. Elder, C. A. Lembi and D. J. Morre, "Toxicity of 2,4-D and Picloram to Fresh Water Algae", JHRP Report, Purdue University, October 1970.

M. Sargeant, D. Blazek, J. H. Elder, C. A. Lembi and D. J. Morre, "The Toxicity of 2,4-D and Picloram Herbicides to Fish", JHRP Report, Purdue University, October, 1970.

*D. J. Morre, "Is 2,4-D Safe?", Proceedings Indiana Plant Food and Agricultural Chemical Conference, Purdue University, 1970.

D. J. Morre and H. H. Mollenhauer, "A Compact and a Dispersed Form of the Golgi Apparatus of Fish Liver". Proceedings of the Indiana Academy of Science for 1970.

*J. H. Elder, C. A. Lembi and D. J. Morre, "Toxicity of 2,4-D and Picloram to Fresh and Salt Water Algae", Proceedings North Central Weed Control Conference, 1970.

M. Sargeant, D. Blazek, J. H. Elder, C. A. Lembi and D. J. Morre, "The Toxicity of 2,4-D and Picloram Herbicides to Fish", Proceedings of the Indiana Academy of Science for 1970.

J. H. Elder, C. A. Lembi, L. Anderson and D. J. Morre, "Scale Calcification in Chrysophycean Algae", Proceedings of the Indiana Academy of Science for 1971.

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Is 2,4-D Safe?

D. James Morré

Department of Botany and Plant Pathology, Purdue University

For the moment, yes! With its relatively low toxicity and its rapid rate of elimination from the animal body, 2,4-D seems to present no serious hazard to man, livestock or wild animals. The toxicity to birds and fish is also low and no effects on reproduction of either birds or other animals has been noted. It is biodegradable and rapidly removed from the environment through the action of microorganisms.

In spite of its almost total non-toxicity to animal and bird life, 2,4-D is a potent herbicide providing control of a broad spectrum of broad-leaved plant species. Conceivably, such a potent herbicide could effect growth of the many microscopic plants or algae that are so important to the ecological balance of our lakes, streams and oceans. The important fact is that it does not! Tests conducted in the Plant and Cell Physiology Laboratory at Purdue University have determined the effect of pure 2,4-D on the growth and reproduction of 16 species of fresh water (4 filamentous greens, 2 non-motile greens, 3 motile greens and 6 blue-greens) and 2 species of marine algae. Tests were at 220 ppm which is near the solubility of 2,4-D in water. In none of the tests, were the organisms killed and in only two species was there even a suggestion of a toxic effect. At 22 ppm, we could see no effect of 2,4-D on any of the species. For comparison, direct or accidental contamination from 3 lb/A of 2,4-D applied directly to 6 inches of water gives a concentration of about 2 ppm. Our results show that the potential hazard of pure 2,4-D to both fresh water and marine algae from contamination of runoff water or even direct or accidental contamination is nil.

Unfortunately, it has been the practice of some investigators and many users of 2,4-D to regard all formulations of 2,4-D as being equal in toxicity to animals. They are not. The chemical form and formulation of the herbicide used is important. This is illustrated by some data on fish given in the table. Clearly, pure 2,4-D and the salt formulations are non-toxic. However, in shallow water, the amount of an ester formulation of 2,4-D required to secure optimum results for weed control might also result in fish kills. The injury to fish would result, not from the basic herbicide, but from materials added to the basic herbicide either in its manufacture or in its formulation. In contrast to esters, the salt and amine formulations sold commercially are about as safe as the parent acid. Even with the toxic ester formulations, the concentrations required to kill algae and fish are 10 to 100 times higher than what might be expected in terms of water pollution resulting from runoff of treated soil or vegetation.

Effect of 2,4-D formulations on green sunfish (Lepomis cyanellus) tested at 110 ppm.

Formulation	Acid Equivalent % of 2,4-D	Average Response Time
2,4-D acid	99	no effect in 41 hours
Lithium salt of 2,4-D	95	no effect in 41 hours
Isopropyl-diethylanolamine salt	28	no effect in 41 hours
Butoxyethanol Ester	43	60 minutes

What about long term effects? These days, we hear about all sorts of different pesticides causing anything from birth defects to heart disease but we don't have enough information to make a final judgement. Conceivably, if enough 2,4-D were fed for a long enough time to just the right organism under just the right conditions it would result in some type of abnormality or undesirable side effect. This can happen with any drug, including common aspirin. If given the choice, I personally would prefer an overdose of 2,4-D to an overdose of aspirin.

One fact which has emerged from all the studies with 2,4-D is that its mode of action is remarkably specific. It is toxic to vascular plants and that is about it. Even here, broad-leaved (dicot) plants are easily killed while grasses, rushes, sedges and lilies (narrow-leaved plants or monocots) are killed only with difficulty.

2,4-D, if not the safest, is one of the safest agricultural chemicals on the market today. It presents low potential hazards to man, livestock, wild animals, birds, fish or microscopic plant life from normal agricultural or industrial use practices. 2,4-D-containing herbicides could be made even safer by restricting their use to non-toxic salt and amine formulations.

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TOXICITY OF 2, 4-D AND PICLORAM TO FRESH AND SALT WATER ALGAE[1]

John H. Elder, C.A. Lembi and D.J. Morre[2]

Growth regulating herbicides are used extensively for control of brush and herbaceous species in non-crop areas as well as in crop situations. In addition to the standard growth-regulating herbicides 2, 4-D (2, 4-dichlorophenoxyacetic acid) and 2, 4, 5-T (2, 4, 5-trichlorophenoxyacetic acid), picloram (4-amino-3, 5, 6-trichloropicolinic acid) has also received extensive testing for similar purposes. The mode of action of picloram is similar to that of 2, 4-D (2, 3), but with a greater herbicidal effectiveness due to increased mobility (3) and resistance to breakdown (5, 6).

The potential hazard of picloram herbicides to fresh water algae or phytoplankton from terrestrial runoff water or direct accidental contamination of water has received virtually no attention, except from the popular press. A single report (4) describes experiments in which 1 ppm of picloram did not retard algal growth. Similarly, results with other growth regulating herbicides on growth of algae are limited.

This paper reports preliminary information on the effects of 2, 4-D and picloram on growth and development of several species of freshwater and marine algae. Such information is required to evaluate the potential threat, if any, of growth regulating herbicides to our environment. Without such information, potentially useful agricultural chemicals may be lost through public or regulatory over-reaction. Alternativley, herbicides may be already entering our lakes, streams and oceans at levels dangerous to their productivity.

Materials and Methods

Picloram (4-amino-3, 5, 6-trichloropicolinic acid, 99% analytical grade), technical picloram (4-amino-3, 5, 6-trichloropicolinic acid, 91% technical grade) or 2, 4-D (2, 4-dichlorophenoxyacetic acid, 99% biological grade) were added directly to the growth media at 10^{-3}, 5×10^{-4}, and 10^{-4} M concentrations. The genera examined are summarized in Table 1. All were fresh water organisms except for the marine Chrysophyta *Coccolithus* and *Pleurochrysis*. Fresh water algae were grown on at least one optimal medium (7) as well as on at least one minimal medium (soil water, pond water or both) under fluorescent lights (150 ft-c) on a 16 hr photoperiod with gentle shaking and at about 25°C. Marine organisms were cultured in an equal mixture of filtered sea water and soil water.

Growth was determined from changes in optical density at 660 mu or from cell counts. Cells were examined with the light microscope for morphological changes and, if morphological changes were detected, with the electron microscope.

Results and Discussion

The solubility of 2, 4-D acid in water is approximately 2.5×10^{-3} M, that of picloram, 1.8×10^{-2} M. Therefore, from a practical standpoint, the highest concentration of herbicide tested was 10^{-3} M (220 ppm 2, 4-D or 240 ppm picloram). Even at this concentration, we could observe no lasting effect on most of the organisms with either 2, 4-D or picloram. In experiments where inhibition of growth was noted at 10^{-3} M, growth was normal at 10^{-4} M. Many of the organisms were cultured for several weeks in the presence of the herbicides and 1 week was the minimum test period.

In the presence of technical picloram, non-motile species were generally less affected than motile species. Motile species were found to lose motility at 10^{-3} M and 5×10^{-4} M but not at 10^{-4}M (24 ppm). Data for *Euglena gracilis* Klebs are given in Table 2. An impurity in the technical picloram, tentatively identified from samples provided by the Dow Chemical Company as 2-(3, 4, 5, 6-tetrachloro-2-pyridyl) guanidine, is the major toxic principle.

Even with technical picloram, not all organisms were affected. *Pediastrum*, for example, grew on technical picloram even at the highest concentrations. In the declining phase of the culture, more colonies were found in the presence of picloram than in its absence or in the presence of 2, 4-D (Table 3). Picloram acid (99%) was generally nontoxic.

The results show that the potential hazard of 2, 4-D or picloram to both fresh water and marine algae is nil from terrestrial runoff water (concentrations of 0.1 ppm or less) or direct or accidental contamination (3 lb/A applied directly to 6 inches of water gives a concentration of about 2 ppm). Further studies will be necessary to determine what effects these herbicides might have on subtle ecological shifts as well as to assess the effect of herbicides in combination with other water pollutants. 2, 4-D derivatives (particularly esters) may be substantially more toxic than the parent acid (1). Salt formulations are much less toxic than the esters. In future studies, we will examine a number of 2, 4-D derivatives in different formulations to seek those which will result in minimum damage to algae, fish and other aquatic organisms since the parent herbicide is relatively non-toxic. There is no evidence for biological magification of either 2, 4-D or picloram in algae (4).

Summary

2, 4-D and picloram exhibit low toxicity to all fresh water and marine algal species examined even at rates approaching the maximum solubility of the herbicides in water. Use of formulated materials (especially esters) increases toxicity. Yet, these herbicides present a low potential hazard to aquatic ecosystems from normal agricultural or industrial practice.

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[1]Joint Highway Research Project. Purdue University Agricultural Experiment Station Journal Paper No. 4251.

[2]Purdue University, Lafayette, Indiana

References

1. Butler, P.A. 1965. Effects of herbicides on estuarine fauna. Southern Weed Conference Proc. (18th) 576-580.
2. Eisinger, W.R., S. Krawiec, D.J. Morré and R.J. Hull. 1968. Picloram: Its auxinic properties and interactions with 2, 4-D. Weed Science Soc. America Proc. 28-29.
3. Eisinger, W., D.J. Morré and C.E. Hess. 1968. Promotion of plant growth by Tordon herbicide. Down to Earth 21: 8-10.
4. Hardy, J.L. 1966. Effect of Tordon herbicide on aquatic chain organisms. Down to Earth 22: 11-13.
5. Keys, C.H. and H.A. Friesen. 1968. Persistence of picloram activity in soil. Weed Science 16: 341-343.
6. Merkle, M.G., R.W. Bovey and F.S. Davis. 1967. Factors affecting the persistence of picloram in soil. Agron. J. 59: 413-414.
7. Starr, R.C. 1964. The culture collection of algae at Indiana University. Am. J. Bot. 51: 1013-1044.

Table 1. Algal Genera Tested.

Division Chlorophyta	Division Chlorophyta	Division Cyanophyta
Order Volvocales	Order Cladophorales	Chroococcus
Chlamydomonas	Pithophora	Cylindospermum*
Pandorina	Order Zygnematales	Merismopedia*
Volvox	Spirogyra	Microcoleus
Order Chlorococcales	Zygnema	Nostoc*
Chlorella	Division Chrysophyta	Oscillatoria
Pediastrum	Coccolithus	Division Euglenophyta
Hydrodictyon	Navicula*	Euglena
	Pleurochrysis	

* Single determination

Table 2. Effect of Herbicides on Euglena gracilis, Z Strain Growing in Soil Water After 3 Days.

Herbicide	Conc.	O.D. 660 mμ	% motile cells
None	–	0.26	100
2, 4-D acid (>99%)	10^{-4}M	0.27	100
Analytical picloram (99% acid)	10^{-4}M	0.26	100
Technical picloram (91% acid)	10^{-4}M	0.23	5
	5×10^{-4}M	0.23	10
	10^{-4}M	0.26	100

Table 3. Effects of Herbicides on Viability of Pediastrum in Pond Water.

		Cells/ml ± standard deviation	
Herbicide	Conc.	After 1 doubling	Two weeks later
None	–	114 ± 14	26 ± 8
2, 4-D acid (>99%)	10^{-4}M	104 ± 10	26 ± 10
Technical picloram (91% acid)	10^{-4}M	112 ± 16	60 ± 10

EVALUATION OF THE ENVIRONMENTAL SAFETY OF ROADSIDE HERBICIDES: LOCATION OF HERBICIDE RECEPTOR SITES ON THE SURFACES OF PLANT CELLS

1. Scope and objectives: The purpose of these studies was to locate specific herbicide receptor sites on the surface of plant cells, develop an assay procedure to determine the presence and approximate number of these sites and to determine if man, fish, domestic animals, phytoplankton, etc. possess these sites. If not, they may totally lack the ability to respond to the herbicide, the ultimate in environmental safety.

2. Introduction: Detailed laboratory studies were initiated in 1969 to develop an assay procedure for herbicide binding sites. Initially, we used the herbicide N-napthylphthalamic acid or Alanap as a model system since this material was known to block one of the initial steps in herbicide action and thought to combine with with herbicide site. More recently, auxin herbicides have been employed.

3. Method of approach: Laboratory techniques of cell fractionation, radioisotope labeling and modified equalibrium dialysis were combined in a series of studies continued over a period of nearly 3 years.

4. Major findings: A binding assay for auxin herbicides was developed and the sites located on the surface membrane of plant cells.

5. Research implementation: Findings have been incorporated into subsequent phases of the project only. This is a major undertaking and several additional years may be required to complete the project.

6. Summary: Studies to determine environmental safety of roadside herbicides at the cellular level were initiated. Progress was made in locating and identifying the binding sites in higher plants.

7. Reports:

C. A. Lembi and D. J. Morre, "Herbicide-Binding Activity of the Plasma Membrane from Grass Coleoptiles", JHRP Report, Purdue University, March 1971.

C. A. Lembi, D. J. Morre, K. St. Thompson and R. Hertel, "N-1-Napthylpthalamic Acid Binding Activity of a Plasma Membrane-Rich Fraction from Maize Coleoptiles", Technical Paper Published in 1971.

F. A. Williamson, D. J. Morre and A. C. Leopold, "Auxin-binding Activity of Plasma-Membrane Rich Fractions from Plant Cells", Technical paper presented at the Midwestern Section of the American Society of Plant Physiologists, Urbana, Illinois, June, 1972.

PART III

DEVELOPMENT OF SPECIFIC NEW WEED CONTROL PRACTICES

COMBINATION TREATMENTS FOR CONTROL OF WILD GARLIC

1. Scope and objectives: To develop chemical or combined chemical and mechanical treatments for control of wild garlic along roadsides.

2. Introduction: To control wild garlic with chemicals an economically feasible method must be found to get the herbicide to the below-ground bulblets. Treatments were designed to enhance the uptake and hopefully the translocation of the herbicides to the system of underground bulblets.

3. Method of approach: Field, greenhouse and laboratory studies were conducted in 1968, 1969 and 1970 to determine susceptibility of wild garlic to various herbicides, application rates required, stage of growth of greatest susceptibility and means of enhancing herbicidal effectiveness.

4. Major findings: 2,4-D alone was found to be superior or equivalent to any of the herbicides or combinations of herbicides tested for control of wild garlic and considerably less expensive. In greenhouse studies, 2,4-D action was enhanced by application of the herbicide in dimethyl sulfoxide (DMSO) as the solvent. This effect was not demonstrated in the field even under conditions where the waxy surface layers of the plants were distrupted mechanically to permit rapid entry of the herbicide in DMSO. Treatments were most effective applied early in the growing season at the 4-5 inch stage of growth. Treatment effectiveness was found to decline with increasing plant height. Treatments became ineffective when the plants were 10 to 12 inches tall at the time of treatment. Mechanical disruption of foliage and pretreating the plants with a carbamate herbicide such as CIPC increased the effectiveness of the 2,4-D but had no long-term effect on garlic plants in the absence of the 2,4-D.

5. Research implementation: These studies which were completed in 1970,

served as the basis for development of CIPC - 2,4-D herbicide combinations for control of wild garlic given in the summary report which follows.

6. Summary: 2,4-D alone at a rate of 1 lb/A or following pretreatment of plants with 1 lb/A of CIPC was most effective in the control of wild garlic when applied early in the growing season at the 4-5 inch growth stage.

Reports:

D. J. Morre, R. D. Cheetham, S. Krawiec and R. D. Clark, "Combination Treatments for Control of Wild Garlic and Common Milkweed", JHRP, Purdue University, October 1970.

2,4-D - CIPC COMBINATION HERBICIDES FOR CONTROL OF WILD GARLIC

1. Scope and objectives: To develop a herbicide treatment for eradication of wild garlic using findings derived from a 3-year preliminary study.

2. Introduction: Greenhouse and preliminary field experiments indicated that pre-treatment of wild garlic with a carbamate herbicide such as CIPC greatly enhanced the killing action of subsequently applied 2,4-D. In 1970, studies were initiated to test the use of 2,4-D - CIPC combinations for garlic control and continued during 1971 and 1972.

3. Method of approach: Field studies were conducted at several locations along Bypass 52 and vacant fields in the Lafayette area. Details are provided with the tables. When possible, treatments were begun in mid-March when the garlic plants were about 4 inches high. In 1971, treatments were delayed until April 26 with considerable loss in treatment effectiveness. Plants were first treated with 1 lb/A CIPC. After growth of about 2 inches had occurred (mid-April), the foliage was bruised to mechanically disrupt the cuticle. For spot treatment, flattening the plants with a lawn rake was effective. For larger areas, a corrugated roller might be used. Immediately following the beating or rolling treatment, 2,4-D was applied at a rate of 1 to 2 lb/A.

4. Major findings: The combination treatment gave complete control of existing wild garlic plants, including primary bulbs, and at least 50% reduction in numbers of secondary bulblets (Tables III and V, Fig. 3). Regrowth was estimated to be less than 10% in 1971 and 30% in 1972 (treatments applied late) (Table IV). Regrowth from the 1972 studies will not be determined until the fall of 1972 and spring of 1973. The plots established in 1970 were resprayed in 1971 so that in the spring of 1972

only a few scattered plants remained in these plots although possibly enough to provide reinfestation in 3 to 5 years. In spite of early indications to the contrary, turf grasses are adversely affected by the treatment (Fig. 4).

Irrespective of results with top growth, effective kill of bulbs by 2,4-D was dependent upon pretreatment of plants with CIPC. In general, CIPC alone had no detrimental effect on bulbs. 2,4-D alone resulted in bulb damage but not enough to provide control. 2,4-D-treated plants frequently produced soft, white bulbs in contrast to the hard, brown bulbs characteristic of untreated plants and plants receiving CIPC alone (Table III). Plants receiving CIPC followed by 2,4-D were characterized by extensive cell division and enlargement of cells in below ground parts which resulted in tumor- or callus-like appearance of bulb tissues. The combination of CIPC followed by 2,4-D caused extensively deformed bulbs which at the time of examination were often decomposing and in many of the roots were dead (Fig. 3). In spite of the synergistic interaction of CIPC and 2,4-D, mechanical disruption of foliage was still necessary to achieve effective control of wild garlic with the combination.

TABLE III

Response of wild garlic (Allium vineale) to CIPC - 2,4-D combination treatments in 1970. Plants were pretreated March 22, 1970 at the 5-inch stage of growth with or without 1 lb/A CIPC followed by treatment on April 16 at the 7 1/2-inch stage of growth with or without 1 lb/A 2,4-D amine in 40 gpa water. Plants in one-half of each treated plot were flattened with a lawn rake to crush the foliage and mechanically rupture surface waxes and cuticle prior to 2,4-D treatment. Evaluations were made on May 28 approximately 6 weeks following the 2,4-D application. Values followed by the same letter are not significantly different.

Pretreatment	Treatment	Plant Height, Inches	% Mature Plants With Flowers	% Mature Plants With Solid I^{o} Bulbs
None	None	22 a	100 a	100 a
	2,4-D	14 b	50 a	86 b
CIPC	None	22 a	100 a	96 a
	2,4-D	12 b	30 b	82 b
	Foliage crushed prior to treatment with 2,4-D			
None	2,4-D	10 b	7 c	50 b
CIPC	2,4-D	9 b	8 c	0 c

TABLE IV

CIPC - 2,4-D Combination Treatments for Control of Wild Garlic in 1971. Treatments were applied under roadside conditions, Tippecanoe County along Indiana 126. Plots were approximately 5 ft x 10 feet and replicated. The garlic was at an average density of 64 clumps/10 square feet with about 6 plants per clump (384 plants/10 square feet). One-half of each plot was beaten with a lawn rake to mechanically crush the plants prior to application of the 2,4-D treatments. Plants in one-half the plots were pretreated with 1 lb/A CIPC on April 26, 1971 when the garlic was 6 to 12 inches high. Mechanical crushing and 2,4-D applications (1 lb/A) were on May 8. Evaluations were on October 3, 1971 and March 12, 1972.

	% Reduction in Regrowth			
	Fall (October 3, 1971)		Spring (March 12, 1972)	
	Foliage		Foliage	
Treatment	Crushed	Not Crushed	Crushed	Not Crushed
Unsprayed	22	22	60% increase	60% increase
CIPC (1 lb/A)	25	25	34*	24*
2,4-D (1 lb/A)	52	24	75	37
CIPC (1 lb/A) followed by 2,4-D (1 lb/A)	59	25	70	46

* Bulbs showed severe signs of CIPC response in the second year.

TABLE V

CIPC - 2,4-D Combination Treatments for Control of Wild Garlic in 1972. Treatments were applied under roadside conditions, Tippecanoe County. Plots were approximately 7 feet x 6 feet. One-half of each plot was beaten with a lawn rake to mechanically crush the plants prior to application of the 2,4-D treatments. Plants in one-half the plots were pretreated with 1 lb/A CIPC on March 18, 1972 when the wild garlic was 4-5 inches tall. Mechanical crushing and 2,4-D applications (1 lb/A) were on April 12 when the garlic was 6-8 inches tall. Final evaluations were on June 1, 1972.

Pretreatment	Treatment	Weight of I^o Bulbs (mg/bulb)	% I^o Bulbs White	% I^o Bulbs Soft
None	None	1.4	0	0
	2,4-D Ester (LV-4)	0.6	70	20
	2,4-D Ester in oil	0.7	70	30
CIPC	None	0.8	0	10
	2,4-D Ester	0.6	100	0
	2,4-D Ester in oil	0.8	100	0
	Foliage crushed prior to treatment with 2,4-D			
None	None	1.1	0	0
	2,4-D Ester	0.6	90	10
	2,4-D Ester in oil	0.5	50	50
CIPC	None	0.6	0	10
	2,4-D Ester	0.5	100	0
	2,4-D Ester in oil	0.4	0	100

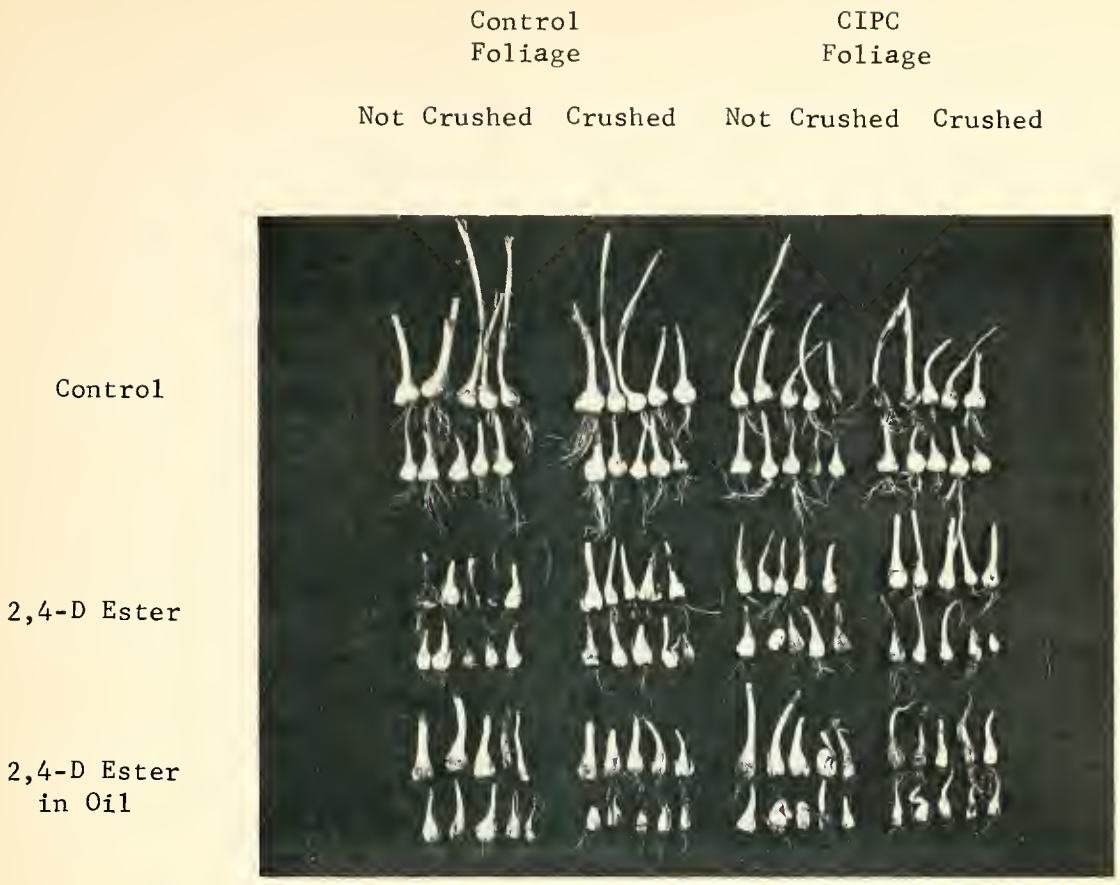

Figure 3. Representative primary bulbs of wild garlic taken from herbicide treatments described in Table V.

Figure 4. Effects of 1 lb/A CIPC applied April 26, 1971 followed by 1 lb/A 2,4-D on May 8, 1971 on bluegrass. Photograph taken June 18, 1972 one year after spraying. Plants at the top of the photograph were untreated for comparison. Plants at the bottom of the photograph from the CIPC - 2,4-D treatment were stunted, wiry in appearance and had much swollen bases and short, thickened roots.

5. Research implementation: Because of the potential injurious effects of the CIPC - 2,4-D combination on turf grasses, testing of this combination treatment will be discontinued except for comparison purposes. Use of 2,4-D with application in non-phytotoxic oils or to mechanically crushed foliage will continue to be explored as potential herbicide treatments for spot treatment of wild garlic.

6. Summary: A combination treatment of 1 lb/A CIPC applied in mid-March followed by mechanical bruising of the foliage and application of 1 lb/A 2,4-D in Mid-April gave complete control of existing wild garlic plants, including primary bulbs, and at least 50% reduction in numbers of secondary bulblets. The treatment may lead to weakening and loss of desirable turf species in treated areas.

7. Reports:

D. J. Morré, R. D. Cheetham, S. Krawiec and R. D. Clark, "Combination Treatments for Control of Wild Garlic and Common Milkweed", JHRP Report, Purdue University, October 1970.

D. J. Morré and R. D. Cheetham, "CIPC - 2,4-D Combinations for Control of 2,4-D - Resistant Monocot Species, JHRP Report, Purdue University, October 1970.

D. J. Morré and R. D. Cheetham, "Response of 2,4-D - Resistant Monocot Species to CIPC - 2,4-D Combinations", Proceedings North Central Weed Control Conference, Lexington, Kentucky, December 1970.

2,4-D - CIPC COMBINATION HERBICIDES FOR CONTROL OF YELLOW NUTSEDGE

1. Scope and objectives: To extend observations on the effectiveness of CIPC - 2,4-D combinations on wild garlic to other difficult-to-control monocot species particularly yellow nutsedge.

2. Introduction: Yellow nutsedge (Cyperus esculentus) is a serious and troublesome turf weed found primarily on low, damp soils. Because it does not grow tall and looks like a grass, it is not a serious weed along roadside except in rare situations where its presence along roadsides might endanger adjacent crop land. The principal value of this study was to determine the generality of the effectiveness of the CIPC - 2,4-D combination on grass-like (monocot) plants.

3. Method of approach: Field studies were conducted at two locations in Tippecanoe County in the summers of 1970 and 1971. Greenhouse experiments were carried out both years. Applications of CIPC and 2,4-D were the same as for wild garlic (preceeding summary report) except that mechanically crushing the foliage was omitted.

4. Major findings: Results in 1970 were encouraging (Table VI). The CIPC pretreatment was on June 1 followed by 2,4-D on June 18 in combination with mowing. Control of nutsedge was excellent (Table VI, Fig. 5) with no regrowth the following season. In 1971, CIPC was applied at rates of 0, 1/2, 1 and 2 lb/A in triplicate plots on April 25 when the nutsedge was 2.3 inches high. On May 8, some of the plots were sprayed with 0, 1/2, 1 or 2 lb/A 2,4-D when the nutsedge was 3.3 inches high. The nutsedge responded to the CIPC - 2,4-D combination as before. After approximately one week the plants began to recover but control was still satisfactory (Figs. 6 and 7). Early applications of the combination to nutsedge does not seem as desirable as for wild garlic.

TABLE VI

Effect of CIPC (1 lb/A) pretreatment on June 1 and 2,4-D (1 lb/A) treatment on June 18 in water (40 gpa) on growth of established yellow nutsedge (Cyperus esculentus) in the field in 1970.

Pretreatment	Treatment	Plant height after 1 week	Plant height after 2 weeks	Growth after 2 months
None	None	7	15	normal
CIPC	2,4-D	4	4	none

Figure 5. Effect of CIPC (1 lb/A) in water followed by 2,4-D (1 lb/A in water) 16 days later on control of yellow nutsedge under roadside conditions. Photograph taken 2 weeks after application of 2,4-D. Procedures are as described for 1971 studies.

Figure 6. Effect of CIPC followed by 2,4-D 13 days later on control of yellow nutsedge in turf. Untreated check. Photographed on June 30, 1972 one year after treatment.

Figure 7. Effect of CIPC followed by 2,4-D 13 days later on control of yellow nutsedge. Treated area photographed June 30, 1972 one year after treatment.

5. Research implementation: None pending further study.

6. Summary: Yellow nutsedge responds to a CIPC - 2,4-D combination treatment by reduced growth and/or death of the plant but does not respond to either CIPC or 2,4-D alone. The findings raise the possibility of a general response of grasses and grass-like plants to 2,4-D - CIPC combination herbicide treatments.

7. Reports:

D. J. Morré, R. D. Cheetham, S. Krawiec and R. D. Clark, "Combination Treatments for Control of Wild Garlic and Common Milkweed", JHRP Report, Purdue University, October 1970.

D. J. Morré and R. D. Cheetham, "CIPC - 2,4-D Combinations for Control of 2,4-D - resistant Monocot Species, JHRP Report, Purdue University, October 1970.

D. J. Morré and R. D. Cheetham, "Response of 2,4-D - Resistant Monocot Species to CIPC - 2,4-D Combinations", Proceedings North Central Weed Control Conference, Lexington, Kentucky, December 1970.

2,4-D - CIPC COMBINATION TREATMENTS FOR CONTROL OF CATTAILS AND AQUATIC SEDGES

1. Scope and objectives: To extend use of 2,4-D - CIPC combination treatments developed for wild garlic to other monocot weeds such as cattail and aquatic sedges.

2. Introduction: Cattail is a weed which is unsightly and troublesome which rapidly invades any poorly drained areas along roadsides where water stands. Along Interstate Highways, poorly drained areas may become clogged with cattails well in advance of the time the highway is opened to traffic. They become established from seed in 1 or 2 years. Sedges are mostly aquatic plants which occur in the same areas where cattails are found.

3. Method of approach: Studies were carried out in 1970 and 1971 in a poorly drained section of Highway 126 in Lafayette, Indiana. In 1970 cattails 4-5 ft high and just beginning to flower were sprayed with 1 lb/A CIPC (40 gpa; 40 psi) on June 2. On June 11, the plots were mowed and 2,4-D at a rate of 1 lb/A (40 gpa; 40 psi) was applied to the regrowth (about 6 in) on June 19. Observations were continued through the summer and the following year. In 1971, the spraying cycle was repeated without the mowing treatment and beginning earlier. CIPC was applied on April 26, 1971 and the 2,4-D was applied on May 8, 1971.

4. Major findings: The treatments were completely ineffective both in 1970 and 1971.

5. Research implementation: The importance of cattails as a roadside weed was emphasized in meetings with highway personnel along with the ease of control by improving drainage and the difficulty of control

through use of chemicals.

6. Summary: The 2,4-D - CIPC combination treatment effective for control of wild garlic and yellow nutsedge was ineffective in the control of cattails and aquatic sedges both in 1970 and 1971. Cattails are easily controlled by improving drainage which seems like the most feasible approach at present in view of ineffectiveness of most chemicals including the CIPC - 2,4-D combination against cattails.

7. Reports: None anticipated pending further study.

GRASS CONTROL IN PAVEMENT CRACKS AND STABILIZED SHOULDERS -- PRELIMINARY STUDIES

1. Scope and objectives: To explore the use of pre-emergence herbicides for removal of vegetation, especially weedy annual grasses, from cracks in pavements and from stabilized shoulders.

2. Introduction: Weed growth in cracks and along stabilized shoulders is thought to significantly shorten the life of these road surfaces. Cost-benefit calculations show that if the life were extended by only one year, the cost of herbicide treatment over a 5-10 year period might be paid for from cost savings. We recognize that a more desirable form of weed control in cracks is to fill the cracks but the stabilized shoulders remain a problem. In 1971, shoulder replacement was estimated to cost $32/mile with an average life expectancy of 7-10 years.

3. Method of approach: Preliminary studies were carried out on Highway 126 in Lafayette, Indiana in the spring of 1972. Balan was applied at a rate of 0.68 lb/A to the pavement only at an application rate of 20 gpa of water on May 9, 1972. In parallel experiments Balan was applied to stabilized shoulder and turf at rates of 1.36 (40 gpa) lb/A and 0.68 (20 gpa) lb/A. Crabgrass was just beginning to germinate at the time of treatment. Treatment effectiveness was evaluated on June 30, 1971.

4. Major findings: Balan at a rate of 0.68 lb/A applied directly to the pavement gave complete control of weedy grasses in pavement cracks (Figs. 8 and 9) but little if any control of grasses on the adjacent stabilized shoulder. Balan applied directly to the stabilized shoulder or to roadside turf at the 1.36 lb/A rate gave 90-100% control of annual weedy grasses with no injury to desirable grasses (Figs. 10 and 11).

Figure 8. Pavement treated with 0.68 lb/A (20 gpa) Balan on May 9, 1972. Note absence of weed grasses from cracks. Photographed June 30, 1972.

Figure 9. Untreated pavement showing numerous annual weedy grasses in cracks. Photographed June 30, 1972.

Figure 10. Roadside turf treated with 1.36 lb/A Balan (40 gpa) on May 9, 1972. Treatment gave 90-100% control of weedy annual grasses with no detremental effect on established turf grasses. Photographed June 30, 1972.

Figure 11. Untreated plot showing numerous annual weedy grasses for comparison. Photographed June 30, 1972.

5. Research implementation: The findings, although preliminary, have been discussed with maintenance personnel. The cost of implementing a grass control program is largely in making the application. By combining the herbicide application with ice and snow removal in the winter (Table VII), the principal cost would be that of the herbicide. This idea has not been received enthusiastically by district personnel and considerable additional testing will be required to determine feasibility.

6. Summary: The effectiveness of pre-emergence herbicides applied to pavement surfaces for control of annual grasses in cracks and on stabilized shoulders was demonstrated.

7. Reports: None anticipated pending further study.

TABLE VII

INDIANA STATE HIGHWAY SNOW AND ICE REMOVAL

July 1, 1970 through June 30, 1971

TONS OF MATERIAL USED		
	Sodium Chloride	226,048.17
	Calcium Chloride	793.00
	Total Tons	226,841.17
COST OF MATERIAL USED		
	Sodium Chloride	$ 2,816,309.11
	Calcium Chloride	40,471.85
	Total Cost	$ 2,856,780.96
AVERAGE COST PER TON		
	Sodium Chloride	$ 12.41
	Calcium Chloride	49.56
TOTAL MILES COVERED		756,137 miles
	Average Pounds Per Mile Used	600 lbs.
OVER ALL COST		
	Material Cost	$ 2,856,780.96
	Man Hour Cost	960,748.51
	Grand Total	$ 3,817,529.47

EFFECT OF AGRICULTURAL GYPSUM ON GROWTH OF TURF GRASSES AND WEEDS

1. Scope and objectives: To investigate the possibility of using agricultural gypsum as an inexpensive method of encouraging the growth of turf grasses and reducing weedy grass species.

2. Introduction: Agricultural gypsum at a rate of 50 lb/1000 square feet or flowers of sulfur at a rate of 20 lb/1000 square feet have been reported to stimulate the growth of turf grasses and discourage the growth of weed grasses expecially with alkaline soils. These chemicals might offer an inexpensive and environmentally safe approach to roadside improvement.

3. Method of approach: Tests were conducted in the spring of 1972 on the Purdue campus to determine the effect of 25, 50 and 100 lb/1000 sq. ft. agricultural gypsum on the growth and vitality of a bluegrass turf and on weed growth. A second test using sulfur at a rate of 20 lb/1000 square feet was established the previous year.

4. Major findings: Neither treatment appeared to offer beneficial effects in proportion to the cost. With the sulfur, some yellowing and stunting of the bluegrass was noted. Final evaluations of the gypsum plots will be made in the fall of 1972.

5. Research implementation: None pending final evaluations.

6. Summary: Agricultural gypsum and sulfur at recommended rates were examined for beneficial effects on turf. Although final evaluations are not scheduled until the fall of 1972, no benefits sufficient to warrant applications of these materials to roadsides have been found.

7. Reports: None anticipated pending further study.

JOHNSONGRASS CONTROL

1. Scope and objectives: To provide a basis for understanding the resistance of Johnsongrass to chemical control measures.

2. Introduction: Johnsongrass is a serious roadside weed problem in the southern 1/3 to 1/2 of the state. The plant is unsightly, obstructs vision, requires repeated mowing and provides a constant threat to adjacent cropland. In terms of dollar value lost, Johnsongrass is the most serious of the state's perennial weeds. Resistant to most chemical treatments, Johnsongrass is not readily controlled by foliage treatment with herbicides.

3. Method of approach: Greenhouse and laboratory studies were carried out over a two-year period under the direction of Prof. Richard Hull to study the translocation patterns and response of Johnsongrass to various herbicide treatments.

4. Major findings: Results show the rhizomes to be susceptible to a variety of herbicides that are ineffective when applied as foliage treatments. Correlated between translocation patterns and killing of rhizomes suggests that failure of the herbicide to reach rhizome buds is a major contributing factor in the lack of effectiveness of herbicides applied to Johnsongrass foliage. Efforts to time applications with various stages of physiological activity of the plants resulted in changes in top kill but did not seem to influence regrowth from rhizomes.

5. Research implementation: These studies were discontinued in 1969 and resumed under an Experiment Station Project directed by Prof. Fred Roeth.

6. Summary: Failure to reach rhizome buds is a major contributing factor in the lack of effectiveness of herbicides applied to Johnsongrass foliage.

7. Reports: No additional report anticipated.

COMBINATION TREATMENTS FOR CONTROL OF COMMON MILKWEED

1. Scope and objectives: A potent new herbicide (Tordon or picloram) providing control of a broad spectrum of plant species was selected for use in combinations with the standard roadside herbicides 2,4-D and 2,4,5-T laboratory, greenhouse and field evaluations lead to development of a chemical treatment for eradication of common milkweed.

2. Introduction: Common milkweed is an abundant roadside species and was not economically controlled by any one chemical or mechanical treatment available at the time these studies were initiated. Common milkweed is particularly unsightly and seems to be most prevalent at intersections where the plants may become sufficiently tall to obstruct vision.

3. Method of approach: Common milkweed (Asclepias syriaca) plants were grown in the greenhouse either from seed or from rhizomes collected from local natural infestations. Laboratory studies were on seedlings. Field studies were conducted in an uncultivated area along Bypass 52 in the vicinity of West Lafayette, Indiana, in the summer and fall of 1967. To evaluate the effectiveness of field applications in controlling below ground parts, rhizomes were sampled at weekly intervals. The entire lateral rhizome system was sampled and vertical rhizomes were sampled to a depth of about 1 foot. After sampling, rhizome pieces were placed in the greenhouse and those producing shoots were scored as viable. After 10 weeks, the rhizomes were removed from the pots and examined for signs of deterioration.

4. Major findings: Application of Tordon plus 2,4-D or 2,4,5-T mixtures to common milkweed plants in the late bloom stage of development (August 15 - 30) at a rate of 2 lbs/A gave best results in terms of control of below ground parts as compared to earlier applications (Table VIII).

TABLE VIII

The effect of 2 lb ae/A of Tordon and 2,4,5-T herbicides alone or in combination on the repression of bud growth of rhizomes collected from plants treated in the field on August 23, 1967. The rhizome systems were sampled from 1 to 8 weeks after spraying.

Acid equivalent percent by weight in mixture applied		Shoots per 15 root segments weeks after spraying						
2,4,5-T	Tordon	1 wk	2 wk	3 wk	4 wk	6 wk	8 wk	Total
0	0	8	16	10	7	7	11	59
100	0	8	6	4	15	9	4	46
75	25	1	1	1	1	3	2	9
50	50	1	1	2	7	1	1	13
25	75	0	0	0	3	0	0	3
0	100	0	0	0	0	0	0	0

Fall is the time of year when the plants normally move organic materials into the below-ground storage parts. An unfortunate aspect of the treatment was that viable seed was still produced by treated plants.

At least 25% of the Tordon herbicide at a given treatment rate was replacable by 2,4-D or 2,4,5-T without a significant decline in overall herbicidal effectiveness (Fig. 12) as compared to Tordon alone. Symptom expression was slower with Tordon than with either 2,4-D or 2,4,5-T. The delayed killing action might facilitate movement of materials into below ground parts, thereby contributing to effectiveness in control of perennial species such as milkweed.

5. Research implementation: These studies were the first to show the value of fall herbicide applications for control of roadside weeds. The findings have since been extended to a number of species and finally implemented in the form of a specific recommendation to the State Highway Commission in the spring of 1971. The finding that up to 25% of a more costly and potent herbicide such as Tordon can be replaced by a less costly but less potent herbicide of similar mode of action will result in considerable cost savings if and when this combination treatment is used for general roadside weed control.

6. Summary: Fall applications of herbicide were superior to spring or summer applications for control of common milkweed. Tordon at a rate of 2 lb/A or a mixture of 1 1/2 lb Tordon plus 1/2 lb 2,4-D applied in late August gave complete control of top growth and underground parts. Up to 25% of the Tordon in a mixture could be replaced less costly 2,4-D at all application rates tested over several species without loss of treatment effectiveness.

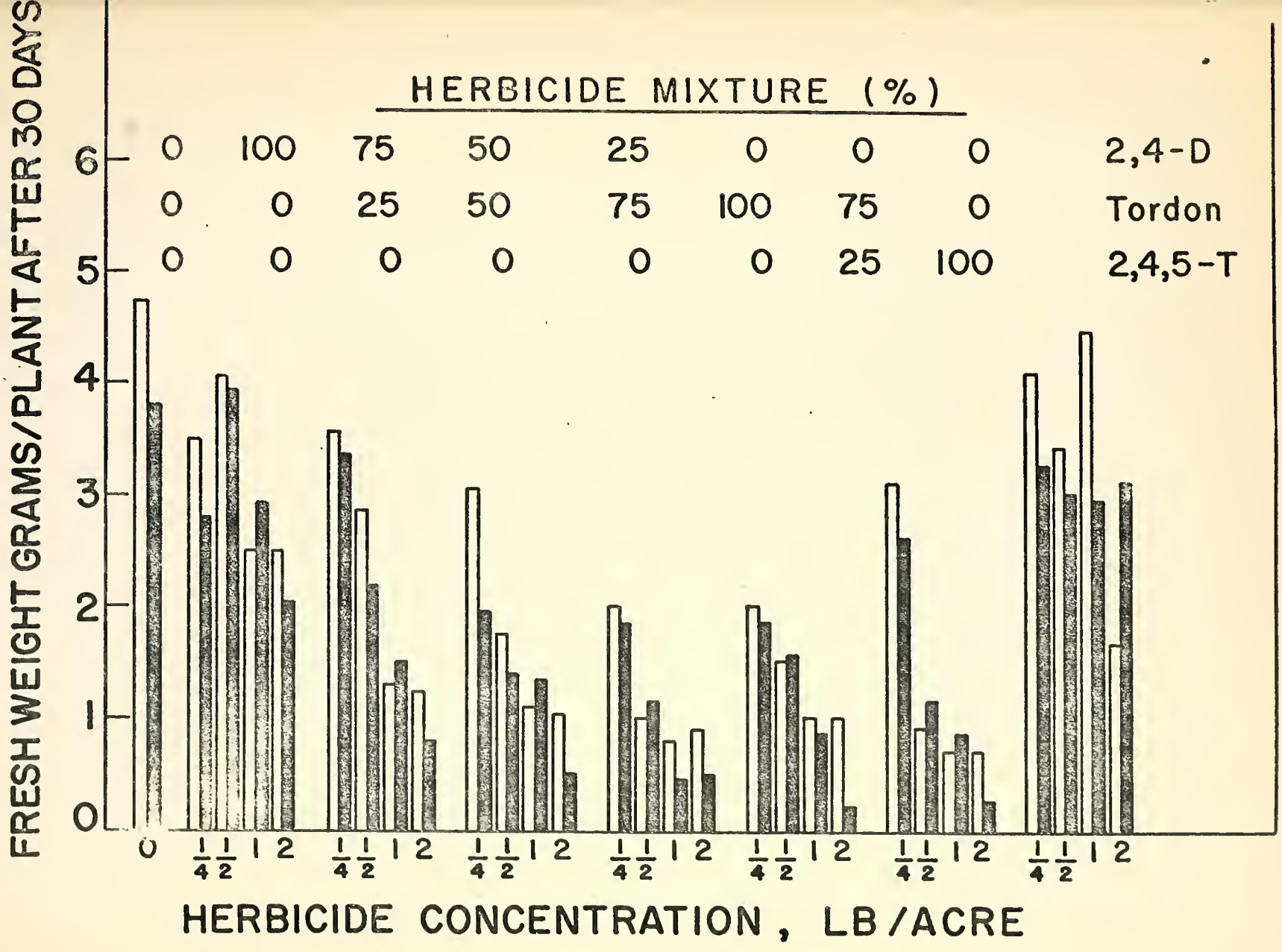
HERBICIDE MIXTURE (%)
0 100 75 50 25 0 0 0 2,4-D
0 0 25 50 75 100 75 0 Tordon
0 0 0 0 0 0 25 100 2,4,5-T
FRESH WEIGHT GRAMS/PLANT AFTER 30 DAYS
0 1 2 3 4 5 6
0 1/4 1/2 1 2
HERBICIDE CONCENTRATION, LB/ACRE

Figure 12. Effect of Tordon herbicide, butyl 2,4-D and butyl 2,4,5-T alone and in various combinations on fresh weight of milkweed plants grown from seed or rhizomes. Plants were 3 to 3.5 months old when treated. ☐ - shoots. ■ - roots.

7. Reports:

D. J. Morre, W. R. Eisinger and H. W. Mussell, "Tordon - 2,4-D - Dimethylsulfoxide Combination Herbicides for Use in Roadside Development", JHRP Report, Purdue University, November, 1967.

S. Krawiec and D. J. Morre, "Interactions of Tordon Herbicide Applied in Combinations". Published in Down to Earth, a publication of the Dow Chemical Company, Midland, Michigan, Winter 1968.

D. J. Morre, R. D. Cheetham, S. Krawiec and R. D. Clark, "Combination Treatments for Control of Wild Garlic and Common Milkweed", JHRP Report, Purdue University, October, 1970.

PART IV

FALL HERBICIDE APPLICATIONS FOR CONTROL OF ROADSIDE WEEDS

FALL HERBICIDE APPLICATIONS FOR CONTROL OF COMMON MILKWEED AND WHORLED MILKWEED

1. Scope and objectives: To determine the effectiveness of a fall application of Tordon - 2,4-D mixtures for control of common milkweed (Asclepias syriaca) and whorled milkweed (A. verticillata).

2. Introduction: Anotomical and physiological studies of common milkweed indicated that a fall herbicide application might prove beneficial for control of this plant species. Fall is a time when latex production is at a minimum so that removal of herbicide into the latex would be minimal. Additionally, fall is a time when herbicides will reach the underground plant parts through the natural translocation activity of the plant. In the fall, nutrients are moved from the above ground parts of the plants in advance of the first killing frost to be stored over winter in the underground parts. In contrast, the reverse occurs in the spring. Nutrients are moved from the underground parts to the growing shoots.

3. Method of approach: Tests were conducted in the fall of 1970. Plots were located along County Farm Road north of Lafayette, Indiana, in an infestation that included both common and whorled milkweed. Tordon - 2,4-D mixtures were applied at the rate of 3/4 lb Tordon plus 1/4 lb 2,4-D per acre and at the rate of 3/8 lb Tordon plus 1/8 lb 2,4-D per acre in 40 gallons of water per acre at 40 psi. Treatments were applied on August 10, 1970. Evaluations were made on October 17, 1970 and the following spring.

4. Major findings: The milkweed plants at the time of spraying were in the late green fruit stage or had failed to fruit because of repeated mowing (Fig. 13A). Two months after spraying all plants were dead (Figs. 13, 14 and 15). Regrowth was prevented only at the high application rate of 3/4 lb/A Tordon plus 1/4 lb/A 2,4-D.

a

b

Figures 13A and B. Untreated plants of common milkweed (A) and common milkweed plants treated with a mixture of 3/4 lb Tordon plus 1/4 lb 2,4-D (B) on August 10, 1970. Photograph taken October 17, 1970.

Figure 14. Plots containing common milkweed treated with a mixture of 3/4 lb Tordon plus 1/4 lb 2,4-D on August 10, 1970 and photographed the following spring.

a

b

Figures 15A and B. Whorled milkweed (Asclepias verticillata) photographed after treatment with a mixture of 3/8 lb Tordon and 1/8 lb 2,4-D per acre applied August 10, 1970. Photographs taken on October 17, 1970 (A) and the following spring (B).

5. Research implementation: These findings were incorporated into the fall herbicide application schedule recommended to the State Highway Commission.

6. Summary: A mixture of 3/4 lb Tordon plus 1/4 lb 2,4-D applied August 10 controlled common milkweed and whorled milkweed.

7. Reports:

D. J. Morre, "Fall Applications Control Next Years Weeds", Proceedings Indiana Plant Food and Agricultural Chemical Conference, Purdue University, 1971.

D. J. Morre, "Minimal Cost Maintenance for Indiana Roadsides", Proceedings 58th Road School, Purdue University, 1972.

FALL APPLICATIONS FOR CONTROL OF CANADA THISTLE, FIELD THISTLE AND BULL THISTLE

1. Scope and objectives: To determine the effectiveness of a fall application of Tordon - 2,4-D mixtures for control of various thistle species.

2. Introduction: Thistles, especially Canada thistle in the northern half of the state, represent one of the more serious roadside weed problems perhaps second only to Johnsongrass. This series of experiments was designed to determine the rate of application of Tordon - 2,4-D mixtures required for fall control of thistle, the effect of mowing on treatment effectiveness and a comparison of the Tordon - 2,4-D ratio determined from greenhouse and laboratory studies with that in a commercially available (Tordon 202) mixture.

3. Method of approach: Experiments were conducted in a roadside, fencerow and adjacent pasture situation north of Lafayette, Indiana. This situation was chosen since it contained a heavy infestation of Canada thistle (Cirsium arvense), bull thistle (C. lanceolatus) and field thistle (C. altissimus). Tordon - 2,4-D mixtures in a ratio of 3 parts Tordon to 1 part 2,4-D were applied at rates of 1/2, 1, 1 1/2 and 2 lb/A. One half of the plots had been mowed with regrowth 8-12 inches high and in early bud stage (Figs. 16 and 17). The remainder of the plots contained mature thistle 3-4 feet high in late bloom stage of development (Fig. 16A). A portion of the adjacent pasture was sprayed with 6 lb/A of Tordon 202 mixture (2 lb/A Tordon plus 4 lb/A 2,4-D) for comparison. Herbicide applications were made on August 10, 1970 and again on October 17, 1970. Evaluations were made in October, 1970 and the following spring and summer.

4. Major findings: Tordon - 2,4-D mixtures at rates of 1 lb/A or more to mature plants (unmowed) gave excellent control of all thistle species studied. Applications to regrowth of mowed plants even at the 2 lb/A rate were considerably less effective. Application of Tordon 202 mixture to regrowth of mowed plants even as late as October 17 was completely ineffective.

a

b

Figures 16A and B. Thistle plots at time of first herbicide application. In A, mowed portions with thistle regrowth are in the foreground with mature plants along the fencerow and roadside (background). B is a closeup view of the mature thistle plants along the roadside. Photographed August 10, 1970.

a

b

Figures 17A and B. Closeup views of thistle regrowth at time of spraying. A. Canada thistle. B. Bull thistle. Photographed August 10, 1970.

5. Research implementation: Fall applications of Tordon - 2,4-D mixtures of 1 lb/A or more were effective for thistle control but not to thistle which had been previously mowed. The tank mix of 3 parts Tordon to 1 part 2,4-D determined from laboratory and greenhouse studies was superior to the commercially available mixture of 1 part Tordon to 2 parts 2,4-D. These findings have been incorporated into a new research project in which fall applications of herbicide will be combined with minimal mowing to provide better weed control at lower cost. It is doubtful if our present practices of repeated and often late mowing of Canada thistle along roadside coupled with even a late fall application of 2,4-D will ever result in thistle control even with repeated treatment cycles. Minimal (and perhaps early) mowing coupled with more potent herbicides (such as Tordon) will be required.

6. Summary: Tordon - 2,4-D tank mixtures in the ratio of 3 parts Tordon to 1 part 2,4-D were superior to commercially available Tordon - 2,4-D mixtures for control of Canada, bull and field thistle. Fall applications to mature, unmowed plants were superior to spring and summer applications and to fall applications to regrowth of mowed plants. Minimal mowing is indicated as an effective aid to thistle control by chemicals.

7. Reports: No additional reports anticipated pending further study.

FALL APPLICATIONS FOR CONTROL OF WILD PARSNIP

1. Scope and objectives: To determine the minimal rate of application and effectiveness of a fall application of Tordon - 2,4-D combinations for control of wild parsnip.

2. Introduction: Wild parsnip is an especially troublesome roadside weed with a biennial growth habit. Plants germinate in the spring and summer to overwinter as a small plant with a whorl of leaves about grass height (Fig. 18). The following spring, the plants produce a flowering stalk up to 5 feet in height which is unsightly, obstructs vision, kills turf by shading and produces abundant seed to ensure reinfestation. Herbicide applications in spring or summer were found to be ineffective in killing the plant or even in preventing the production of viable seed since the plant grows rapidly in early spring. It is frequently in full flower by May 15. We reasoned that the time to control wild parsnip was in the fall when the plant was in its overwintering stage. This approach to control of biennial weeds was tested and found to be effective.

3. Method of approach: Plots were located on McCormick Gravel Road near the Purdue Campus. Spring applications were made on July 18, 1970 at a rate of 1 1/2 lb Tordon (44 K) plus 1/2 lb 2,4-D per acre. Fall applications were made to an adjacent area in the second week of August, 1970 at rates of 1/2, 1, 1 1/2 and 2 lb/A of a mixture of 3 parts Tordon and 1 part 2,4-D. Evaluations were in October 1970, October 1971 and July 1972.

4. Major findings: Nine weeks after treatment, the mixture of Tordon plus 2,4-D gave 92, 98, 100 and 100% control of wild parsnip at the 1/2, 1 1/2 and 2 lb/A rates respectively (Fig. 19), with no substantial re-infestation either one or two years later (Fig. 20).

5. Research implementation: The findings were incorporated into the fall application schedule recommended to the State Highway Commission.

Figure 18. Plants of wild parsnip germinate in the spring and summer and overwinter as small plants with whorls of leaves about grass height. At this stage they are extremely susceptible to herbicides and can be most easily controlled by fall applications. Photographed on October 17, 1971.

Figure 19. Wild parsnip plots 9 weeks after spraying. The 1/2 lb/A rate of Tordon plus 2,4-D is on the left with an unsprayed plot on the right. The 1 lb/A rate is in the background. Even the lowest rate of 1/2 lb/A was 90% effective in control of wild parsnip. The 1 lb/A rate gave 98% control.

Fig. 20. Wild parsnip plots on July 25, 1972 approximately 2 years after herbicide treatment. In this photograph, the unsprayed area in on the left showing numerous mature plants of wild parsnip 4-5 feet high which have produced seed. The treated area on the right is still weed free.

6. Summary: A mixture of 3/4 lb Tordon plus 1/4 lb 2,4-D applied in mid-August to wild parsnip gave complete control of this weed the following two seasons while a spring application of twice the amount of herbicide did not provide even single season control.

7. Reports:

D. J. Morre, "Fall Applications Control Next Years Weeds", Proceedings Indiana Plant Food and Agricultural Chemical Conference, Purdue University, 1971.

D. J. Morre, "Minimal Cost Maintenance for Indiana Roadsides", Proceedings 58th Road School, Purdue University, 1972.

TORDON - 2,4-D MIXTURES FOR CONTROL OF ROADSIDE WEEDS -- A 3-YEAR EVALUATION

1. Scope and objectives: A series of demonstration plots were established on McCormick Gravel Road near the Purdue University campus to evaluate the lasting effectiveness of single fall application of a Tordon plus 2,4-D mixture for control of roadside weeds. Final evaluations are scheduled for October 1973.

2. Introduction: The effectiveness of the Tordon plus 2,4-D mixture applied to roadsides in the fall indicated the possibility of a 3-year spraying rotation in which one herbicide application might suffice for a 3 year period. With that objective in mind, plots were established in the fall of 1970 to evaluate the lasting effectiveness of treatments over a 3 year period. Data is complete only for the second season but visual observations suggest that third season control of most species will be adequate.

3. Method of approach: Triplicate plots were sprayed at rates of ½, 1, 1½ and 2 lb/A of a mixture of 3 parts Tordon to one part 2,4-D in mid-August 1970 (Fig. 21). Weed counts were taken before and 9 weeks after spraying and again in the fall of 1971. Additional counts are planned for the fall of 1972 and the fall of 1973.

4. Major findings: All species were controlled the first season by applications of the Tordon plus 2,4-D mixture at rates of 1 lb/A or greater. The ½ lb/A rate gave 75 to 90% control of most species except wild carrot and common milkweed which were not controlled. Evaluations one year later indicated lasting control for most species except nodding spurge which is a low growing summer annual which germinates from seed (Table IX). For practical purposes, the sprayed plots were still weed-free one (Figs. 22 and 23) and two years (Figs. 24 and 25) after spraying.

TABLE IX

Effectiveness of a fall application of Tordon (3 parts) plus 2,4-D (1 part) mixtures on control of roadside weeds the following season. Treatments were applied in mid-August 1970 and counts were taken October 7, 1971. Data is given in plants per 100 square feet.

		Rate of application of total herbicide mixture			
Weed species	Check	1/2 lb/A	1 lb/A	1 1/2 lb/A	2 lb/A
Wild carrot	16	2	0	0	0
Buckhorn plantain	119	1	0	0	0
Rough cinquefoil	6	0	0	0	0
Common milkweed	3	0	0	0	0
Wild parsnip	1	0	0	0	0
Broad-leaf plantain	8	0	0	0	0
Whorled milkweed	3	0	0	0	0
Black medic	12	0	0	0	0
White clover	10	0	0	0	0
Yellow woodsorrel	5	0	0	0	0
Nodding spurge	29	9	15	9	9
Composites	6	0	0	0	0

Figure 21. Appearance of test plots in 3-year evaluation prior to spraying in early August, 1970. Wild carrot was especially abundant and unsightly.

Figure 22. Check plot photographed in August, 1971 approximately 1 year after spraying. The weed situation was virtually unchanged from that shown in Figure 21, even though the plots had been mowed several times.

Figure 23. Plot treated with 1 lb/A of a mixture of 3 parts Tordon and 1 part 2,4-D in August 1970 and photographed in August 1971. The plots remained essentially weed free for the entire season.

Fig. 24. Check plot photographed in July 1972 approximately 2 years after spraying. Even though the area was recently mowed, growth of wild carrot, buckhorn plantain and other weeds is evident. Photographed July 25.

Fig. 25. Treated area photographed in July 1972 approximately 2 years after spraying. The plots remain essentially weed free indicating lasting weed control for a minimum of 3 years following a single application. Photographed July 25.

5. Research implementation: The findings to date have been incorporated into the fall application schedule recommended to the State Highway Commission in the spring of 1971 and implemented in the fall of 1971.

6. Summary: Tordon (3/4 lb/A) plus 2,4-D (½ lb/A) applied in combination in mid-August gave complete control of all perennial and biennial weed species for one full season. The results point to the possibility of a 3-year spraying rotation in combination with reduced-cycle mowing to give an annual cost saving of an excess of $800,000 in the contract program alone and without deterioration of existing turf.

7. Reports:

D. J. Morre, "Fall Applications Control Next Years Weeds", Proceedings Indiana Plant Food and Agricultural Chemical Conference, Purdue University, 1971.

D. J. Morre, "Minimal Cost Maintenance for Indiana Roadsides", Proceedings 58th Road School, Purdue University, 1972.

E. FALL APPLICATIONS: COMPARISONS OF VARYING RATES OF 2,4-D, DICAMBA AND TORDON

1. Scope and objectives: To compare varying rates of 2,4-D with varying rates of two experimental herbicides Dicamba and Tordon for weed control under actual conditions of contract application.

2. Introduction: Physiological studies showed that perennial weeds are most susceptible to herbicides in the fall. This is the time when the plants are storing up food reserves in their underground parts. As the first killing frost approaches, these plants move available materials, including herbicides, into these underground parts. Underground parts must be killed to achieve control of these weeds. By applying the herbicides in the fall, the herbicides will reach the underground parts through the natural translocation activity of the plant at a time when these parts are most susceptible to the killing action of the herbicide. Biennials, plants which develop from seed the first year and then overwinter in a rosette stage to flower and cause serious problems the following year, are also controlled by a fall application. The rosette stage is an ideal time to control biennial species as was shown by investigations with wild carrot and wild parsnip. Also controlled by a fall application were winter annuals which germinate in the fall, grow through the winter and flower in the spring or early summer if the application is made very late. Dandelion, plantain, buckhorn, creeping charlie and other short-lived perennials common to turfed areas were found to be especially susceptible to fall applications of herbicide.

An important advantage of the fall application is that safety to desirable plants in nearby cropland, or gardens or to trees, shrubs and flowers is maximal since the growing season is over. By the following

spring, soil residues are completely dissipated especially with the biodegradable 2,4-D herbicides.

Some details of fall applications are still being developed but generally from September 1 until the first killing frost seems to be the time to make the applications. Where winter annuals are not a problem, applications during August have been very effective against perennials and biennials.

3. Methods of precedure: Plots were located on Ind. 24 near Wolcott and on Ind. 47W near the junction with U.S. 421. 2,4-D was applied at rates of 1, 2, 4, 2.7, 5.4 and 10.8 lb/A. A mixture of 3 parts Tordon and 1 part 2,4-D was applied at rates of 1, 2 and 4 lb/A as was a similarly proportioned mixture of Dicamba plus 2,4-D. Treatments were applied using conventional truck-mounted equipment by Chemitrol, a contractual herbicide application service operating out of Indianapolis, Indiana. Applications were on October 1, 1971 on Ind. 24 and on October 4, 1971 on Ind. 47.

4. Major findings: Tordon - 2,4-D combinations continue to look most promising with 100% control at a rate of 3/4 lb Tordon plus 1/4 lb 2,4-D. Dicamba at the same rate of application also gave excellent weed control as did 2,4-D (Table X). Yet, even at the highest rates tested, neither 2,4-D or dicamba were particularly effective in eradication of either milkweed or canada thistle. The most recent evaluations taken in mid-July 1972 show considerable reinfestation of 2,4-D and Dicamba plots with dandelion seedlings but levels of weed control remained high at 50 to 80% depending on rate of application. Final evaluations will be in the fall of 1972.

5. Research implementation: The findings to date have been transmitted to Marion Bugh, Maintenance Landscape Supervisor, Indiana State Highway Commission. Evaluations in progress in other parts of the state suggest

that a spring application of 2,4-D will control many of the seedlings which emerge in the wake of the fall application.

6. Summary: At one-third the rates of application, combination herbicides of Tordon plus 2,4-D or dicamba plus 2,4-D consistently outperformed 2,4-D alone although fall applications of 2,4-D gave excellent weed control. Because of the safety factor, it was recommended that amine formulations of 2,4-D be retained in the spraying program by contract as the material of choice for at least one additional year.

7. Reports: A complete report on this phase of the research will be made available to the Maintenance Division in the fall.

TABLE X

Control of perennial weed species by fall applications of 2.7 lb/A 2,4-D applied using convential truck-mounted equipment by Chemitrol, a contractual herbicide application service. Applications were on October 4, 1971 with evaluations on December 4, 1971.

	Plants/100 square feet	
Weed species	Check	2,4-D
Dandelion	588	71
Plantain	155	3
Wild parsnip	211	0
Curled dock	19	0

F. STATE-WIDE TESTING OF A FALL APPLICATION OF 2,4-D IN THE SPRAYING PROGRAM BY CONTRACT

1. Scope and objectives: To obtain data representative of approximately 1,500 linear miles of highway throughout the State of Indiana which received a fall application of 2,4-D between September 15 and October 15, 1971 (Table XI).

2. Introduction: To properly evaluate the effectiveness of a fall application of 2,4-D in the spraying program by contract, it was considered essential to obtain actual weed count data.

3. Method of procedure: Appropriate check plots were established with several tests in each subdistrict. The sampling procedure developed in Part I of this report was used. Observations were begun with initial counts in the fall of 1971 and observations will continue into spring and fall of 1972.

4. Major findings: Initial evaluations of tests of fall applications of 2,4-D at the recommended rate of 2.7 lb/A showed that the treatment gave approximately 90% control of all annual, biennial and short-lived perennial weeds present at the time of spraying including dandelion, buckhorn, common plantain, wild carrot, wild parsnip and curled dock. Top growth of canada thistle and milkweed was also killed but final control estimates of these species must rely on regrowth data to be obtained in the summer and fall of 1972.

Evaluations of the Fall 1971 Contract Spraying Program were made with the cooperation of Mr. Melvin Calvert of the Landscape Division, Indiana State Highway Commission. As of December 23, weed control in the Greenfield, Crawfordsville, Vincennes and LaPorte Districts was consistently good, ranging from 80% to greater than 90%. However, weed

control in the Fort Wayne and Seymour Districts was unsatisfactory in some areas. On I-65 south from Indianapolis, we observed less than 30% weed kill with a 5-6 ft. strip next to the pavement which had apparently not been sprayed. On Ind. 7 south of junction U.S. 31 and Ind. 7, one side of the road showed 100% kill while on the opposite side of the same road, a 4 ft. strip next to the pavement was again unsprayed. On U.S. 31E, a 7 ft. strip next to the fence was unsprayed. On Ind. 46 SE of Columbus, the right hand side of the road showed 100% kill but the left hand side of the road showed no evidence of being sprayed. One strip averaged 1.6 dandelions/square foot nearly two months after spraying. Similar problems were encountered in the Fort Wayne district.

Since in those areas where difficulty was encountered with the contract program, one side of the road or part of the sprayed road showed satisfactory to excellent control, it is impossible to blame the chemical, the weather or the time of application for the bad results. In some cases, wide strips next to the pavement or next to the fence were either unsprayed or inadequately covered by the spray pattern. In other cases, the roads were either never sprayed, sprayed with no 2,4-D in the tank, or sprayed at excessive speeds so that the application rate was below the minimum required for symptom development in the sprayed vegetation.

5. Research implementation: As a result of preliminary evaluation of contract spraying operations this fall, Ind. 105 in the Fort Wayne District was resprayed at no additional expense to the State. Through Marion Bugh, Landscape Supervisor and Melvin Calvert, Assistant Landscape Supervisor, other examples of inadequate applications of herbicide in the contract spraying program have been made known to the Division of

Approved_____

Governor's Office
Mr. Ruel W. Steele, Chairman
Mr. James F. Dumas, Vice-Chairman
Mr. Harry B. Brown
Mr. Harold O. McCutchan
Mr. R. H. Harrell
Mr. N. W. Steinkamp
Mr. Gene K. Hallock
Mr. Edwin J. Simcox
Mr. Eugene Behmer
Mr. P. F. Gibson

GIBSON AGENDA
DIVISION OF MAINTENANCE

ITEM_____

The Chief, Division of Maintenance, is presenting the following Herbicide Treatment Program for Commission consideration, and is requesting authority to prepare contracts and advertise for bids.

TABLE XI
S U M M A R Y
HERBICIDE TREATMENT PROGRAM BY CONTRACT FOR 1971

DISTRICT	CENTER LINE MILES	ACRES	NUMBER OF GALLONS	ESTIMATED COST
Crawfordsville	88.45	477.0	286.2	$ 2,854.75
Fort Wayne	228.44	905.2	539.1	5,377.95
Greenfield	365.40	1,461.0	876.0	8,138.10
LaPorte	268.50	1,926.7	1,156.0	11,531.10
Seymour	189.39	2,375.6	1,425.3	14,217.70
Vincennes	344.62	1,103.5	662.1	6,604.40
TOTAL	1,484.80	8,249.0	4,944.7	49,324.00

This program will be a one spray application. This application is to be made between September First and first killing frost.

The chemical to be used is 2,4-D Amine Form (Low Volatile) and meets the requirements of the Dept. of Agriculture, the U. S. Public Health Service, the Indiana State Chemists and complys with the provisions of the Indiana State Herbicide Law of 1961.

The office of the U. S. Secretary for Environmental Control has not restricted this material for public use. Further this program has been recommended by the Dept. of Botany and Plant Pathology, Purdue University (Dr. D. James Morre, Professor). Funds for this work are available in the current Fiscal Year Budget.

A detailed breakdown of this program by Sub-Districts is available in the Central Office, Division of Maintenance.

Paul F. Gibson
Chief, Division of Maintenance

Maintenance, Indiana State Highway Commission.

6. Summary: Evaluations of the Fall 1971 Contract Spraying Program were encouraging with weed control ranging from 80% to greater than 90% in the one to two months following application. Final evaluations will be in the fall of 1972.

7. Reports: A complete report on this phase of the research will be made available to the Maintenance Division in the fall.

PROGRESS IN IMPLEMENTATION OF A STATE-WIDE PROGRAM OF FALL HERBICIDE APPLICATION

The first formal meeting to discuss research implementation was held with Mr. Marion Bugh, Landscape Supervisor, Indiana State Highway Commission on April 13, 1971 at which time an implementation-seminar program was initiated. Also participating in the planning sessions were Mr. Melvin Calvert and Mr. H. L. Collins of the Indiana State Highway Commission. On May 10, 1971, a meeting was held with the District Maintenance Engineers at the State Highway Commission Offices in Indianapolis. At that time, research progress was reviewed and specific suggestions for improvements in spraying procedures were presented. Existing roadside weed problems were reviewed as well as the spray materials which were available and safe from an environmental standpoint. This meeting eventually led to the adoption of the fall spraying schedule as part of the Spraying Program by Contract with the initial treatments applied in the fall of 1971.

On June 8 and June 9, 1971, the first in a series of Roadside Spraying Seminars was held at the State Highway Commission Research and Training Center, McClure Park, Lafayette, Indiana. At that time the following operational procedures were adopted:

Material: 2,4-D Amine form concentrate containing at least 4 pounds acid equivalent per gallon and meeting the requirements of the Indiana Herbicide Law, the specifications of the Indiana State Highway Commission and the

registration requirements of the Indiana State Chemist. Ester formulations of 2,4-D and 2,4-D plus 2,4,5-T mixtures were withdrawn from use due to possible environmental hazards.

Rate: The material was recommended to be mixed at the rate of 2 gallons of 2,4-D concentrate to 100 gallons of water. The rate represented an increase from 1.5 gallons (final application rate of 2.7 lbs/A).

Schedule of application: The complete herbicide program was reduced from 3 to 2 applications. The periods during which each of the two applications were to be made are Spring application: March 15 to April 30.
Fall Application: September 1 to first killing frost. These application times were selected so that 2,4-D would be most effective in controlling existing roadside weeds, to allow sufficient time to complete the work, to occur at a time when damage from drift to desirable plants in roadside plantings or areas adjacent to roadsides would be minimal, and to permit most efficient use of the contractor personnel and equipment. No applications were scheduled from May 1 until September 1 and the view was expressed that the spring application might be eliminated as well depending on the experienced effectiveness of the fall application.

A second seminar was held on January 18, 1972. Again District Landscape Supervisors, Contractors and representatives of the major chemical companies were present as well as weed control Extension Specialists from the University. Discussed at this meeting were problems of spray drift and control devices, environmental safety, improvements in the mowing program and the effectiveness of the fall application schedule. Plans for a new minimal, low-cost maintenance program to be implemented over the next 5 years was presented. It will combine mechanical and chemical methods in such a way as to maintain

a healthy turf at the lowest possible cost to the state.

Based on figures for 1970 provided by Mr. Marion Bugh, the direct cost saving to the State of Indiana from the Herbicide Treatment Program by Contract was approximately $60,000 annually from the implementation achieved to date. This does not include increased weed control, reduced mowing costs or the 30% reduction in spraying costs by District personnel if the recommendations are implemented at the District level. The costs savings will approximately double in the event that the fall application schedule is improved to the point that the spring application can be eliminated. Should the eventual goal of a 3-year spraying rotation in combination with one-cycle mowing be implemented, the annual cost saving is estimated to be in excess of $300,000 in the contract program alone (mowing and spraying) and without deterioration of existing turf(Table XII).

INDIANA STATE HIGHWAY COMMISSION

INDIANAPOLIS, INDIANA 46204
INTER-DEPARTMENT COMMUNICATION

July 6, 1972

MEMORANDUM

TO: Mr. P. F. Gibson
Chief, Division of Maintenance

FROM: Mr. M. L. Bugh
Landscape Supervisor

Based on the recommendations of the Department of Botany and Plant Pathology, Purdue University, Dr. James D. Morre, Professor, we are submitting a preliminary proposal for a Herbicide Treatment Program.

Further this proposal is in accordance with the proposed research study, "A low cost maintenance program for Indiana Roadsides, a joint highway research project No. C-36-48 F, dated May 16, 1972.

Generally this program would entail a Herbicide Treatment applications, the first application beginning September 15th, the second application, May 15th. The formulation of 2-4-D and rates of applications would be in accordance with the universities recommendations.

These applications would be made on all roads in twelve (12) of the Sub-Districts representing approximately 1/3 of the highway mileage. The overall plan being to apply this program to the entire state over a three (3) year period.

Coupled with this, the program would require the elimination of one (1) mowing cycle on all roads receiving an application of Herbicide.

Detailed quantities and projections are shown on the attached tabulation sheet.

MLB:md

TABLE XII

ESTIMATED COSTS AND COST-SAVINGS OF A 3-YEAR SPRAYING ROTATION WITH ALTERNATING FALL AND SPRING APPLICATIONS OF 2,4-D AMINE

Sub-District	Miles	AC/MI	ACRES	GAL. 2,4-D PER AC.	TOTAL GALS. 2,4-D	EST. COST PER GAL.	TOTAL COST 1 APP.	APP.	TOTAL 3 YEAR PERIOD	TOTAL ANNUAL COST	SAVING ELIMINATION OF MOWING CYCLE		1	ANNUAL SAVING	SAVING ELIM. 1 MOWING 3 yr. per.	NET SAVING 3 year
Linton	289.19	6	1,735	.8	1,388	10.00	13,880	2	27,760	9,253	1,735	9.82	17,038	7,785	51,114	23,354
Paoli	276.37	6	1,658	.8	1,306	10.00	13,060	2	26,120	8,706	1,658	9.82	16,281	7,575	48,843	22,723
Linn Dist.																
Total	565.56		3,393		2,694		26,940		53,880	17,960	3,393		33,319	15,359	99,957	46,077
Plymouth	347.38	6	2,084	.8	1,667	10.00	16,670	2	33,340	11,113	2,084	9.60	20,006	8,893	60,018	26,678
Winamac	247.85	6	1,487	.8	1,189	10.00	11,890	2	23,780	7,926	1,487	9.60	14,275	6,349	42,825	19,045
LaPorte Dist.																
Total	595.23		3,571		2,856		28,560		57,120	19,040	3,571		34,281	15,242	102,843	45,723
Warsaw	367.28	6	2,204	.8	1,763	10.00	17,630	2	35,260	11,753	2,204	10.45	23,031	11,278	69,093	33,833
Goshen	319.06	6	1,914	.8	1,531	10.00	15,310	2	30,620	10,206	1,914	10.45	20,001	9,795	60,003	29,383
Ft.Wayne Dist.																
Total	686.34		4,118		3,294		32,940		65,880	21,960	4,118		43,032	21,073	129,096	63,216
Ridgeville	372.64	6	2,236	.8	1,789	10.00	17,890	2	35,780	11,926	2,236	10.76	24,059	12,133	72,177	36,397
Anderson(S)	298.25	6	1,790	.8	1,432	10.00	14,320	2	28,640	9,546	1,790	10.76	19,260	9,714	57,780	29,140
Anderson(I)	52.59	8	421	.8	337	10.00	3,370	2	6,740	2,246	421	10.76	4,529	2,283	13,587	6,847
Total(And.)	350.84		2,211		1,769		17,690		35,380	11,793	2,211		23,789	11,996	71,367	36,987
Crawfordsville Dist.																
Total	723.48		4,447		3,558		35,580		71,160	23,720	4,447		47,848	24,129	143,544	72,534
Craw'lle(S)	262.83	6	1,577	.8	1,262	10.00	12,620	2	25,240	8,413	1,577	8.63	13,609	5,196	40,827	15,587
Craw'll.(I)	80.32	8	482	.8	386	10.00	3,860	2	7,720	2,573	482	8.63	4,159	1,586	12,477	4,757
Tot.C'lle	323.15		2,059		1,648		16,480		32,960	10,986	2,059		17,768	6,782	53,304	20,344
Frankfort(S)	228.95	6	1,374	.8	1,099	10.00	10,990	2	21,980	7,326	1,374	8.63	11,857	4,531	35,571	13,591
Frankfort(I)	33.10	8	164	.8	131	10.00	1,310	2	2,620	873	164	8.63	1,415	542	4,245	1,625
Tot.Fr'frt.	262.06		1,538	.8	1,230	10.00	12,300	2	24,600	8,200	1,538	8.63	13,273	5,073	39,819	15,219
Crawfordsville Dist.																
Total	585.21		3,597		2,878		28,780		57,560	19,186	3,597		31,041	11,855	93,123	35,653
Seymour(S)	302.62	6	1,816	.8	1,453	10.00	14,530	2	29,060	9,686	1,816	10.69	19,413	9,727	58,239	29,179
Seymour(I)	32.81	8	262	.8	210	10.00	2,100	2	4,200	1,400	262	10.69	2,800	1,400	8,400	4,200
Tot. Sey.	335.43		2,078		1,663		16,630		33,260	11,086	2,078		22,213	11,127	66,639	33,379
Bloom'ton	327.71	6	1,966	.8	1,573	10.00	15,730	2	31,460	10,486	1,966		21,016	10,530	63,048	31,588
Seymour Dist.																
Total	663.14		4,044		3,236		32,360		64,720	21,573	4,044		43,229	21,657	129,687	64,967
State Tot.	3,819		23,170		18,516		$185,160		$370,320	$123,440	23,170		$232,750	$109,315	$698,250	$327,930

CONCLUSIONS

With the development of the Interstate System, the management of turfed roadsides has become an increasingly important function of the Highway Department. Divided lanes, median strips and broad rights-of-ways are an integral part of the design of the modern highway and the management of turfed roadsides is no longer a minor consideration of roadside maintenance.

What happens when roadsides are not maintained in a turfed or semi-turfed condition? Even with careful landscaping and restricted mowing, areas which are not maintained will revert back to natural and native vegetation. Tall weeds and wild grass will kill the turf by shading only to die back during the winter to leave patches of bare soil open to erosion. In as little as one year, our observations reveal that tree seedlings and root sprouts will become established on unmaintained rights-of-way and, after a number of years, add a hazardous condition to an otherwise safe highway. When this happens, the trees will have to be removed at considerable expense and the turf reestablished to prevent additional erosion. The cost of tree removal and reestablishment of turf will far exceed the cost of a modest annual maintenance program.

Implementation of research results obtained under the Joint Highway Research Project has established the effectiveness of fall applications of herbicides to control problem weeds along roadsides. Applications are made from September 1 until the first killing frost. Only environmentally safe amine forms of the herbicide 2,4-D are required. As the first killing frost approaches, hard-to-kill, perennial weeds move all available materials into the underground parts. Herbicides applied at this time will reach the underground parts through the natural translocation

activity of the plant at a time when these parts are most susceptible to the killing action of the herbicide. Dandelion, plantain, buckhorn, creeping charlie, wild carrot, wild parsnip, milkweed, Canadian thistle, dock and other problem roadside weeds are among those most susceptible to fall applications.

An important advantage of fall applications of herbicides is that of environmental safety. In the fall, desirable plants in cropland or gardens, shrubs and flowers in lawns, golf courses or recreational areas and in roadside plantings have completed their growth and are either dying, dead or dormant. Trees and shrubs are loosing their leaves, and unlike the plants to be controlled, escape the herbicide. Problems of drift onto soybean or tomato fields are eliminated since the growing season is over. By the following spring soil residues are completely dissipated especially with the biodegradable herbicide 2,4-D.

In 1971, approximately 1,500 linear miles of highway received a fall application of 2,4-D between September 15 and October 15 under the Spraying Program by Contract. Evaluations of test plots throughout the state showed the treatment to be extremely effective with weed control ranging from 85% to over 95%. Implementation of the fall spraying program resulted in a direct cost saving to the State of Indiana from the Herbicide Treatment Program by Contract alone of an estimated $60,000 annually. These figures do not include increased weed control and safety or reduced mowing costs.

Other research projects completed include development of spot treatments for localized infestations of problem weeds; evaluation of mowing practices; vegetation control in cracks and on stabilized

shoulders; made of herbicide action studies; and evaluation of herbicides for environmental safety. Mechanical and chemical methods combined provide a 3-year (environmentally safe) spraying rotation with minimum mowing to give even greater cost savings and without deterioration of existing turf.

Rights-of-ways are designed for safety and convenience. They should be kept as corridors of open turfed areas to provide the features of safety, beauty and convenience for which they were intended. Maintenance of these broad turfed areas by mechanical and chemical methods must continue. We must maintain a healthy turf along Indiana roadsides but at the lowest possible cost to the State.